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EVALUATION OF NUCLEAR ASPHALT CONTENT GAUGES

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

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16. Abstract

This study evaluated the accuracy and precision of the Troxler, Model 3241-C, and CPN, Model AC-2, Nuclear Asphalt Content Gauges.

To achieve precisions at ±0.15% 95% of the time, it was necessary to establish special procedures for making test samples, controlling environment, and calibration.

Both gauges provided acceptable results utilizing a 3-point calibration. Their use in the field would be acceptable when the proper procedures are followed.

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EVALUATION OF NUCLEAR ASPHALT CONTENT GAUGES

FINAL REPORT

DEPARTMENT STUDY NO. 88-1

Prepared By
MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
DIVISION OF MATERIALS AND RESEARCH

MARCH, 1989

In Cooperation With

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

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INTRODUCTION

The initial intent of this study was to determine if a Nuclear Asphalt Content Gauge is at least as accurate as the current method used for asphalt content determination of a bituminous mixture. The current method used by the department is AASHTO T-164 "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures", Method A, with a stated precision of 0.52% for single operator results. The gauge selected to be evaluated in the study proposal was manufactured by the Troxler Electronics Laboratories, model number 3241-C. It was intended for this gauge to replace the chemical extractions for samples submitted for asphalt content determination only. The extraction procedure is not suitable for the field because it involves the use and disposal of chemicals of a hazardous nature that would create control and disposal problems.

After this study was established, the CPN Corporation was discovered to make a gauge very similar to the Troxler and it was decided the CPN gauge should also be evaluated. Two different gauges would allow the evaluation of how the mechanics of a gauge could differ but produce the same results. The addition of the second gauge added no additional time or cost to the study since the gauge was

loaned for the study by the CPN Corporation and the test samples, once made, could be used in both gauges.

The study began by exploring the capabilities of the gauges in terms of how environment, sample temperatures, and sample preparation affected gauge operation in determining the asphalt content. Then Phase 1 of testing began in which the calibration process used for the gauges was explored. This phase consisted of testing several samples in each gauge to determine the number of points needed to obtain a calibration with the 0.10% precision thought possible by the gauges. Samples were made and tested in each gauge once. Then the results were combined in several ways to derive various combinations of asphalt content point calibrations to determine the number of asphalt content points necessary to produce a calibration.

After comparing the precision of each gauge at various combinations of points for calibrations, it was decided that a 3-point calibration was adequate.

Phase 2 of the precision analysis was done to continue the evaluation of additional types of aggregates and mixtures along with the effects of moisture and aggregate gradation. The curves used in this phase were both 3-point and 4-point. The 4-point curves were evaluated to continue the analysis

of whether the linear or quadratic analysis was most adaptable to the function between the asphalt content of a mixture and the counts the gauges derived from a mixture.

With the additional data that was collected in Phase 2 it was decided that the 3-point calibration curves would provide the precision desired. This would provide a calibration process requiring the minimal amount of manpower, equipment, and space needed to perform the calibrations.

GAUGE OPERATION

The basic principal of operation for both gauges is that thermalized neutrons are counted by detectors. The source of Neutrons is a 100mCi of Americium 241:Beryllium located in the bottom of the gauges. It yields 220,000 Neutrons per second. The test samples are placed directly above the source and below the counters. The counters are three Helium-3 tubes. The Neutrons that are not thermalized sufficiently are not detectable by the Helium-3 tubes. Neutrons are thermalized by colliding with the atoms of other elements. The larger the atomic mass of the element the more collisions that are necessary to thermalize the Neutrons. The Neutrons have to collide 19 times with a Hydrogen atom to be thermalized for counting by the detectors. In comparison to the Hydrogen atom, the Oxygen atom will only thermalize the Neutrons if they collide 158 times with the Oxygen atoms. The presence of the Hydrogen in the asphalt cement is what enables the gauges to determine the asphalt content.

Background

Proper operation of the gauge requires that the number of thermalized Neutrons in the area the gauge is to be operated in be accounted for. This is termed "Background Count" by the Troxler and "Standard Count" by the CPN. The Troxler allows a background to be determined based on a count period

of the operator's choosing from 1 to 16 minutes. The longer the count period used, the greater the accuracy of accounting for thermalized Neutrons in the area. The CPN uses thirty half minute counts, back-to-back, averaged to determine the "Standard Count". This is essentially what the Troxler does internally by breaking down a 16-minute test into several count periods.

Environment Stability

The area the gauges are operated in has to be stable enough to provide a normal distribution of thermalized Neutrons. This is termed as "Gauge Stability" and is determined by each gauge with a ratio that expresses the areas fit to a normal distribution of thermalized Neutrons.

For the Troxler it is an independent operation called a stability test that determines this ratio. It uses 20 counts back-to-back to determine the gauge stability due to the environment. The length of the counts can be 1 minute to 16 minutes. In the study, the 1-minute count period was used to determine the acceptability of the environment, since this was the closest count period to the CPN. The 20 counts done by the Troxler gauge are used to determine a ratio which the manufacturer recommends being between 0.31 and 0.71 with a 0.5 being the perfect condition.

The CPN gauge determines a Chi ratio each time that it determines a "Standard Count" which is the CPN's term for background. The gauge takes thirty half minute counts back-to-back and from these counts determines an average background count and the Chi ratio. This ratio by the manufacturer's recommendations should be between 0.75 and 1.25 with a 1.00 being the perfect condition.

Gauge Equations

A varying number of points are used by the gauges to develop the curve equations needed to determine the asphalt content. The Troxler uses 2 to 12 points to analyze a curve and the CPN uses 2 to 9 points. The Troxler uses a quadratic equation analysis for curves that have 4 or more points in the curve analysis. A linear analysis for the curve determination is used by the CPN for all number of points and the Troxler for 2 and 3 point curves.

The equations used by the gauges are as follows. The linear or quadratic variables are derived by the gauges when data is entered.

Troxler

% Asphalt = A1 + A2/1000*X + A3/10,000,000*X*X

X= Counts on Sample
A1= Intercept for Linear or Coefficient for Quadratic
A2= Slope for Linear or Coefficient for Quadratic
A3= Coefficient for Quadratic

CPN

$$\% \text{ Asphalt} = \frac{X-B+(C-S)}{A}$$

X= Counts on Sample
A= Slope
B= Intercept
C= Background, Counts at Calibration
S= Background, Current

Background is accounted for internally in the Troxler by adding the mathematical difference between the background at calibration and the current background. This same function is shown in the equation for the CPN.

Equation's Acceptability

The manufacturers use a "Fit Coefficient" to describe the curve's degree of precision. Troxler recommends a "Fit Coefficient" of 0.95 to describe a curve that is acceptable. CPN recommends a "Correlation of Fit" of 0.995 to determine a curve's acceptability. The data being purposely spread along the X axis allows these coefficients to give an indication of the curves percent error. The percent error for an equation is more indicative of its ability to predict an answer from the data than the fit coefficient.

The proper operation of these gauges is essential in obtaining the greatest precision possible. The understanding of how the gauges work and the procedures to use in their operation is a must to obtain consistent results.

TESTING ENVIRONMENT

The stability of the environment in which the gauges are operated is critical to the degree of accuracy that can be obtained by the gauges. Even if the environment is kept constant there is still a deviation in background counting due to the naturally present Neutrons.

Environment Stability Evaluated

Before testing began it was necessary to establish if the selected gauge operation locations were acceptable. The built in checks for stability were used to establish whether the rooms selected were stable enough to operate the gauges in and to determine if these checks would be adequate to determine the stability of a field location. It was believed that by being separated by 15 feet, the gauges could be operated in the same location without any loss of precision. The background counts were elevated by the presence of each gauge but the limited testing preformed showed no harmful effects by this close proximity. The gauges were not operated in the same location during the study since both of the manufacturers were uncomfortable with the gauges being located so close to each other and there was inadequate time to evaluate completely the effects of the gauges located so closely together.

The stability ratio for each gauge in their respective rooms was determined. The stability ratios determined by the Troxler ranged from 0.42 to 0.60 which was within the range given by the manufacturer as being acceptable. The stability ratios determined by the CPN ranged from 0.81 to 1.17 which was within the range given by the manufacturer as being acceptable.

The gauges were switched between rooms to check their stability in each other's room. They performed equally well in each of the rooms so there was no bias between the gauges results by using the different rooms.

The gauges were tried in a room with several overhead steam pipes and close to a boiler room. In this room the gauges were unable to obtain stability ratios in the ranges that were allowed by the manufacturers. This showed that the selection of the proper location for operation of the gauges and the continual monitoring for changes in this location is essential for accurate results.

For both gauges it was established that the area they were operated in had to be kept constant in terms of the Hydrogen and Neutron bearing material. The addition of containers of asphalt cement near the gauges elevated the background count from the count before the containers were present. The presence of the containers of asphalt cement were not

harmful to the process but their movement could add variability to the test area that could effect the gauges precision. The occupation of the room during background counting and counting of samples had to be kept as constant as possible. The effect of people walking within 15 feet of the gauges was not understood until Phase 2 was completed and the results of Phases 1 and 2 were compared. The control of persons coming near the gauges was not controlled as strictly in Phase 1 as in Phase 2.

Background Variability

When the study began it was assumed by comparing the variation in counts in the stability tests that the background could affect the gauge counts by 200 on the CPN and 30 on the Troxler. These assumptions were substantiated by analyzing the daily background counts that were performed during the study. Thirty background counts were taken for analysis of the deviation of the counts for a 16 minute counting period. The CPN deviated 99% of the time within ± 96 counts. The Troxler deviated 99% of the time within ± 28 counts. The data used to determine these deviations is shown in Appendix A. The difference in count numbers between gauges is explained by the fact that the CPN counts are not factored down internally at the same rate as the Troxler counts. The ratio of a background count of the CPN to a background count of the Troxler is approximately the same ratio of the values stated above.

SAMPLE PREPARATION PROCEDURES

The bituminous mixtures used were previously approved for work done in the 1988 construction season. The materials were gathered from the production stockpiles during the production of the mixtures. The type of mixtures tested were as follows:

Types A,B,& C.....	Missouri Standard Specifications, Section 403
Type C..... (Trap Rock-Limestone)	Materials And Research Special Provision 5B
Type C..... (Limestone-Steel Slag)	Material And Research Special Provision 6A
Type C..... (Limestone-Gravel)	Materials And Research Special Provision 27
Types IB & IC.....	Materials And Research Special Provision 40A

These mixtures are the highest quality mixtures used by the department. The mixtures material composition and original job mix formula number are shown in Table 1.

The preparation of the samples was the same for all the mixtures. The preparation of samples is not specified in ASTM D 4125 "Asphalt Content of Bituminous Mixtures by Nuclear Method", so it was decided that the samples should

TABLE 1
MIXTURES USED IN STUDY

STUDY IDENT NUMBER	ORIGINAL MIX NO.	MIXTURE COMPOSITION
11.10 11.20	B87-240 C87-241	Crushed Jefferson City Dolomite Blended Asphalt Sand Mineral Filler AC-20 Asphalt
11.11 11.21	B88-296 C88-299	Crushed Kimmswick Limestone Blended Asphalt Sand Mineral Filler 60-70 Asphalt
11.13 11.23	B88-447 C88-450	Crushed St. Louis Limestone Blended Asphalt Sand Mineral Filler AC-20 Asphalt
11.14 11.24	B88-484 C88-286	Crushed Plattsmouth Limestone Blended Asphalt Sand Mineral Filler AC-20 Asphalt
11.15 11.25	B88-318 C88-286	Crushed Burlington Limestone Blended Asphalt Sand Mineral Filler AC-20 Asphalt
11.16* 11.26*	B88-350 LSG88-102	Crushed Gasconade Dolomite Crushed Crowley Ridge Gravel Blended Asphalt Sand Mineral Filler AC-30 Asphalt

TABLE 1
MATERIALS USED IN STUDY
(CONTINUED)

STUDY IDENT NUMBER	ORIGINAL MIX NO.	MIXTURE COMPOSITION
11.17	X88-105	Crushed Plattsmouth Limestone Crushed Kimmswick Limestone Blended Asphalt Sand AC-20 Asphalt
11.27	X88-120	Crushed St. Louis Limestone Crushed Kimmswick Limestone Blended Asphalt Sand Hydrated Lime AC-20 Asphalt
11.30	LSS88-129	Steel Slag Crushed St. Louis Limestone Blended Asphalt Sand Mineral Filler AC-20
11.40	TRL88-133	Crushed Porphyry Crushed St. Louis Limestone Blended Asphalt Sand Mineral Filler AC-20 Asphalt
11.50	A88-138	Crushed Porphyry Blended Asphalt Sand Hydrated Lime 60-70 Asphalt

* Original mixture used a crushed Williamsville Dolomite aggregate. None was available so the Gasconade Dolomite was substituted to conduct the study.

be prepared as specified in AASHTO T-167 "Compressive Strength of Bituminous Mixtures" which is a standard procedure used in preparing specimens for characteristic determinations during the mix design process. A question about this procedure was raised as to the necessity of a butter batch.

Evaluation of Butter Mix

The procedure used to check the loss attributed to starting with an unbuttered bowl was as follows:

> The beater and bowl were weighed clean. The aggregate was added to the bowl and a weight determined. The asphalt cement was added to the aggregate and another weight determined. The sample then was mixed for 2 minutes. The bowl and beater were cleaned as they would be between each sample. The bowl and beater were then weighed again.

The weight loss from the mixture was great enough to change the original calculated percent asphalt content from 3.54% to 3.26% if all the loss was assumed to be asphalt cement. If only half of the loss was assumed to be asphalt cement, the percent asphalt content would change to 3.39% from 3.54%. Either change is significant and it was determined that the butter batch was necessary.

Asphalt Cement Retention

It was questioned whether a higher percent of asphalt cement content might leave more residue on the bowl and beater than would be retained on the bowl and beater with a lower percent asphalt cement content sample. This could be possible but was not explored by actual testing. It was visually observed that from the low point of 3.6% asphalt cement content to the high of 7.0% there was visually no more material retained at 7.0% than at 3.6%. If more asphalt cement was retained and a higher percent mix was made before a lower percent one the calculation of the asphalt content could be affected since the higher percent asphalt content mix would leave more asphalt cement for the mixture with a lower percent asphalt content to absorb. To minimize any possibility of error the lowest percent asphalt content sample was made first and the remaining samples were made in an upward sequence based on increasing percent asphalt content. This type of loss or gain is not addressed in ASSHTO T-167 and is believed to be insignificant.

Sample Test Size

To determine the weight of material needed to fill the testing pan it was decided to follow the manufacturer's recommended procedure which was to fill a testing pan with a graded sample without asphalt cement. This determination was done with the graded samples that were to be the 4.0% asphalt content sample for Phase 1 and the 4.4% sample for

Phase 2. These gradations were close to the middle of the gradation ranges to be tested and approximately the approved job mix formula gradation. The weight determined was rounded to the nearest 10 grams for Phase 1 mixtures. This weight could be changed easily by adding material to the edges where it was difficult to evenly grade the larger particles. It was also determined after mixing some of the samples that a weight rounded to the nearest fifty grams could be compressed into the testing pan. In Phase 2, the weights were rounded to the nearest fifty grams.

It was necessary that the sample size be determined and held constant for each sample of a mixture so the density of the sample would remain constant. During testing, the binder mix weights ranged from 7220 grams to 7650 grams with an average weight of 7431 grams. The Limestone Surface Mixtures ranged from 7050 grams to 7650 grams with an average of 7329 grams. The Special Mixtures with Trap Rock or Steel Slag aggregate required a weight increase to sufficiently fill the testing pan due to a higher unit weight. They ranged from 8150 grams to 8550 grams. The variation in weights within similar types of mixtures and aggregate combinations was small. It could be possible to establish a constant weight for each type mixture and only vary from the constant weight when the aggregate gradation or unit weight vary from the norm.

Sample Mixture Preparation

The aggregate used to make a sample was batched by individual fractions for each sieve No. 10 and larger. The material passing the No. 10 sieve were not sieved into individual fractions. A sample size of 8000 grams was used for most of the mixtures. For a few mixes the sample size was increased because they contained aggregate with higher unit weights. The goal was to obtain a sample size approximately 500 grams larger than what was necessary to fill the testing pan, which has a volume of four quarts.

The aggregates,asphalt cement, and mixing bowl were heated to 325 $\pm$ 5 degrees Fahrenheit for mixing.

The butter batch was mixed at the low asphalt content and discarded. Each sample's aggregate weight was then determined and recorded. The predetermined amount of asphalt cement was added and the weight of the aggregate and asphalt cement was determined and recorded for each sample. These weights were then used to determine the percent of asphalt content actually in the sample. These weights were determined with an electronic scale reading to the nearest tenth of a gram. This ensured accuracy of the asphalt content determination to a hundredth of a percent.

The samples were mixed with a mechanical mixer for two minutes with a wire whip in a 20-quart mixing bowl. Two

minutes is the maximum time required by AASHTO T-167 and provided ample mixing of the mixture.

Sample in Testing Pan Preparation

After mixing, the mixture was placed in a tared pan. Mixture was then removed from the sample until the predetermined weight was reached. The sample was then placed into the testing pan with a scoop. As the mix was placed into the testing pan a spatula was used to move the mixture out to the edges. Care was taken not to exert pressure on the sample with the spatula. The mixture was piled above the top of the pan. Care was taken to spread the mix to the edges so an even head of material was above the pan's top edge. A piece of plywood was then pressed by hand onto the top of the sample. Then the sample was placed on the floor and was stood on to compress the sample to the top of the testing pan. This process helped insure uniform homogeneity of the sample in the testing pan.

The sample was then weighed to determine if the proper weight had been achieved. It was desired to achieve a one gram tolerance in the sample size from what was established for the mixture. The weight was adjusted, if necessary, by adding or subtracting material to obtain the proper weight. Normally, an adjustment of no more than 10 grams was necessary to obtain the desired weight.

The consistent preparation of samples helped ensure that the results derived were accurate and consistent as possible. The preparation of samples was one step in the process of producing good results from the gauges. With the sample now prepared, testing could begin.

TEMPERATURE EFFECTS

The gauges are capable of automatic internal adjustment for the temperature of a sample. It was decided to test the gauges' ability to adjust the counts at different temperatures. It was also tested to see if holding samples at a constant temperature or reheating the samples from room temperature could affect the counts produced.

Temperature Variation

The procedure used to test the effect of temperature change was done with two samples of a Type C mixture made at 4.0% asphalt content from a Kimmswick Limestone. Both samples were tested at six temperatures from 77 to 325 degrees, Fahrenheit. As the data in Table 2 shows, both gauges showed no effect due to the changes in temperature . They counted the samples at the same count number at all temperatures. This is stated with the understanding that, as shown in a previous section, the background changes constantly. The change in background count of $\pm$ 96 for the CPN and $\pm$ 28 for the Troxler was the allowable difference applied to the separate tests.

TABLE 2
TEMPERATURE VARIATION

TROXLER

Temperature*	Counts	Difference From Average	Difference From Low Point
SAMPLE 1			
317	2784	10	30
267	2754	-20	0
231	2800	26	46
215	2756	-18	2
150	2776	2	22
77	2772	-2	18
Average	2774		
SAMPLE 2			
321	2754	5	29
274	2750	1	25
237	2769	20	44
215	2750	1	25
150	2743	-6	18
77	2725	-24	0
Average	2749		

CPN

Temperature*	Counts	Difference From Average	Difference From Low Point
SAMPLE 1			
332	9927	-78	0
268	10028	23	101
248	10021	16	94
225	10046	41	119
139	10007	2	80
82	10003	-2	76
Average	10005		
SAMPLE 2			
330	9877	-60	0
267	9965	28	88
254	9965	28	88
222	9961	24	84
139	9918	-19	41
82	9936	-1	59
Average	9937		

* Degrees Fahrenheit

Constant Heating

The effects of heating a sample constantly or allowing a sample to cool to room temperature and then be reheated to a molding temperature was evaluated. Four Type C mixtures at 4.0% asphalt content were made from a St. Louis Limestone. The two in Set 1 were kept at a constant 255 degrees Fahrenheit and the two in Set 2 were heated to 255 degrees Fahrenheit before testing but then were stored at room temperature in the interim. The Set 2 samples were reheated but were not remolded each time(The 255 temperature would be sufficient enough to mold samples from a loose field sample). The samples were tested each 24-hour period for a total of 5 testings. The results are shown in Tables 3 and 4 for this testing.

The only effect noticed by the extended heating was that the 6.0% and 7.0% samples settled into the testing pans as the mixture settled to a uniform level. These asphalt contents were higher than normal for the aggregate and mixture grading. The extended heating induced flowing of the asphalt cement into the voids. Even with the settling, the samples were counted consistently by the gauges.

The sample sets showed no effects by either method of temperature storage. It would be acceptable that, if a sample was taken in the field and for some reasons unable to be tested, the sample could be kept in a various number of

ways and tested later without any detrimental effects to the test results.

Which answered a scheduling question for this study. If a sample were made and not tested immediately it could be saved and tested the following day or hours later. This was not to be a common practice, but used in case of an emergency, would prevent having to remake a sample.

TABLE 3
CPN CONSTANT HEATING

ELAPSED TIME	2 HOURS	26 HOURS	50 HOURS	71 HOURS	96 HOURS
Set 1					
Sample 1A	10225	10682	10339	10269	10352
Sample 1B	10312	10821	10475	10401	10329
Set One Average	10269	10752	10407	10335	10341
Background	6191	6353	6270	6282	6258
Avg - Bkg	4078	4399	4137	4053	4083
Difference From 4053	25	246	84	0	30
Set 2					
Sample 2A	10286	10705	10317	10347	10282
Sample 2B	10136	10585	10227	10293	10233
Set Two Average	10211	10645	10272	10320	10258
Background	6191	6353	6270	6282	6258
Avg - Bkg	4020	4292	4002	4038	4000
Difference From 4000	20	292	2	38	0

TABLE 4
TROXLER CONSTANT HEATING

ELAPSED TIME	2 HOURS	26 HOURS	50 HOURS	71 HOURS	96 HOURS
Set 1					
Sample 1A	2756	2756	2773	2751	2750
Sample 1B	2775	2735	2758	2765	2770
Set One Average	2766	2746	2766	2758	2760
Background	2286	2304	2287	2295	2287
Avg - Bkg	480	442	479	463	473
Difference From 442	38	0	37	21	31
Set 2					
Sample 2A	2747	2759	2765	2763	2760
Sample 2B	2747	2743	2747	2747	2753
Set Two Average	2747	2751	2756	2755	2757
Background	2286	2304	2287	2295	2287
Avg - Bkg	461	447	469	460	470
Difference From 447	14	0	22	13	23

PHASE 1

This initial phase was to establish the number of points necessary to calibrate the gauges to achieve the precision that would be necessary to use the gauges in the field. A Type B and C mixture from both a Plattsmouth and Burlington Limestone were used in Phase 1.

All of the samples were tested with a 16 minute count period to achieve the greatest accuracy the gauges were capable of. Seventeen or 18 samples for each of the four mixtures were made. They ranged in asphalt content from 3.6% to 7.0% when designed.

Curve Development

The method used in this study made it possible to evaluate a larger number of curve combinations and made the comparison of curve combinations more accurate, since the influence of background was eliminated from biasing the differing curves. All samples were first tested in the CPN gauge and then the Troxler gauge. The counts derived by the gauges were recorded and are shown in Appendix B. The percent asphalt content point combinations used to make the curve combinations in Phase 1 are shown in Table 5. Curves 1 to 10 and 11 to 20 use the same asphalt content points except that 11 to 20 also uses a 0.0% sample.

TABLE 5
CURVES USED IN STUDY

Curve Number	Points
PHASE 1	
1	4.0,5.0
2	4.0,7.0
3	4.0,5.0,6.0
4	4.0,5.0,6.0,7.0
5	3.6,4.0,4.4,4.8
6	3.6,4.0,4.4,4.8,5.2
7	3.6,4.0,4.4,4.8,5.2,5.6
8	3.6,4.0,4.4,4.8,5.2,5.6,6.0
9	3.6,4.0,4.4,4.8,5.2,5.6,6.0,7.0
10	3.6,3.8,4.0,4.2,4.4,4.6,4.8,5.0,5.2,5.4,5.6,5.8
11	0.0,4.0,5.0
12	0.0,4.0,7.0
13	0.0,4.0,5.0,6.0
14	0.0,4.0,5.0,6.0,7.0
15	0.0,3.6,4.0,4.4,4.8
16	0.0,3.6,4.0,4.4,4.8,5.2
17	0.0,3.6,4.0,4.4,4.8,5.2,5.6
18	0.0,3.6,4.0,4.4,4.8,5.2,5.6,6.0
19	0.0,3.6,4.0,4.4,4.8,5.2,5.6,6.0,7.0
20	0.0,3.8,4.0,4.2,4.4,4.6,4.8,5.0,5.2,5.4,5.6,5.8
21	3.6,4.4,5.2,6.0
22	3.6,4.4,5.2
PHASE 2	
1	3.6,4.4,5.2,6.0
2	3.6,4.4,5.2

Curves 10 and 20 were not used in the CPN gauge due to it's limit of 9 points for a curve.

The calculated percent asphalt content and the recorded gauge counts were then entered into the gauges so the gauge could analyze and determine a curve that would best fit the data. With the variables determined for the curves and a count from a check sample, the percent asphalt content could be determined. This was done mathematically outside the gauges. The counts of the check samples were used in the equations to determine the percent asphalt content of the samples. This eliminated the need to recount samples numerous times against different curves in the gauges. It also made the comparison of curve results unbiased due to background variability. The curve data that was generated is shown in Appendix C for the CPN and Troxler gauges.

Analysis of Check Samples Against Curves

The results of the check samples derived from the curves developed were used to determine the "Index of Precision" for each curve combination for each gauge. The "Index of Precision" was determined by "Analysis of Variance" that paired the gauge equation results with the calculated percent of asphalt content. Table 6 shows the indexes determined if the remaining samples that were not used to establish the curve for a particular mixture were used as check points of the curve. Some of the points used to check the curves were outside the boundaries of the points used to define the curves. It was thought that by limiting the check points to ones that were within the limits of the points

used to make the curves that the precision would increase. Table 7 shows the results of this evaluation. In some of the curves, it showed an increase in precision when this was done. In no case was precision lost. Therefore it was determined that the calibration curves would have to consist of points that encompassed the possible asphalt contents to be tested.

The curves using the 0.0% asphalt content point were evaluated to determine if using the point would increase the precision of the equations. It was a point that would only add a single count time to the calibration process. As shown in Tables 6 and 7, it did not increase the numerical precision of the equations. In some cases, it was detrimental to the precision of the equation. This was due to the fact that the use of the 0.0% point caused the equation to use a different Y intercept and slope than it developed without the point. This point was outside the limits to be tested and, since it did not significantly add to the precision of the calibration equation, it was not used.

TABLE 6
PHASE 1 CURVE PRECISIONS

Curves with Phase 1 data with all extra points used as checks.

Curve Number	INDEX OF PRECISION Troxler 95%	Troxler 99%	CPN 95%	CPN 99%
1	.30	.45	.35	.53
2	.17	.26	.27	.41
3	.20	.30	.29	.44
4	.18	.26	.27	.40
5	.06*	.09*	.54	.82
6	.19**	.29**	.40	.60
7	.38	.57	.30	.45
8	.21	.31	.31	.47
9	.19	.28	.12	.19
10	.32	.49	-	-
11	.61	.92	.61	.92
12	.50	.75	.70	1.05
13	.20	.30	.55	.82
14	.17	.26	.49	.73
15	.42	.64	.85	1.28
16	.31	.47	.75	1.13
17	.25	.38	.65	.98
18	.20	.31	.60	.90
19	.18	.27	.17	.25
20	.20	.29	-	-

* Curves T-14-5 and T-15-5 were not included in the Analysis of Variance since they were quadratic equations in which the equation curved the line back towards the Y axis before encompassing all the data points to be checked.

** Curve T-14-6 was not included for the same reason as stated above.

TABLE 7
PHASE 1 CURVE PRECISIONS

Curves with Phase 1 data with all extra points used as checks that were within the upper and lower limits established by the points used to make the curve.

Curve Number	INDEX OF PRECISION Troxler 95%	Troxler 99%	CPN 95%	CPN 99%
1	.19	.28	.17	.19
2	.17	.26	.28	.43
3	.15	.22	.18	.26
4	.17	.25	.15	.23
5	.06*	.09*	.14	.21
6	.19**	.29**	.12	.17
7	.18	.28	.11	.16
8	.18	.28	.14	.22
9	.19	.28	.12	.19
10	.20	.30	-	-
11	.24	.37	.19	.28
12	.50	.75	.70	1.05
13	.18	.27	.33	.50
14	.17	.26	.49	.73
15	.21	.32	.20	.30
16	.21	.31	.20	.31
17	.19	.29	.22	.33
18	.18	.27	.28	.42
19	.18	.27	.17	.25
20	.19	.28	-	-

* Curves T-14-5 and T-15-5 were not included in the Analysis of Variance since they were quadratic equations in which the equation curved the line back towards the Y axis before encompassing all the data points to be checked.

** Curve T-14-6 was not included for the same reason as stated above.

It was determined, from the results of testing in this phase, the use of a 3-point curve would be sufficient to develop calibration curves. The use of the 0.0% point was ruled out and it was decided that the percent asphalt content points used to develop the curves would have to have a spread greater than the points to be tested.

The question of whether a linear or quadratic equation was more precise was still not resolved in this phase. It was determined that this needed further evaluation.

Phase 2 was to proceed by continuing to develop 3-point and 4-point curves with the point combinations shown for Phase 2 in Table 5. Phase 1 data was also evaluated on the Phase 2 curve point combinations by curves 21 and 22.

PHASE 2

This phase was to further test the 3-point and 4-point curves and check the precision of the gauges with other types of aggregates. The samples were made in the same manner as described in the sample preparation section. The samples were prepared and tested the same way as the Phase 1 samples except that the access of personnel to the areas used for testing was more restrictive than in Phase 1. The effects of moisture in the samples and the effects of varying the gradation of the samples from the approved job-mix formula were tested. The ability to transfer a calibration from a laboratory gauge to a field gauge was also explored.

Curve Results Analysis

The continued analysis of the linear verses the quadratic equations in the Troxler showed that the quadratic analysis did not yield precisions significantly more precise than the linear analysis. These precisions are shown in table 8. This was true no matter what phase or mixture combination was being evaluated. The CPN gauge obtained the same precision between the 3-point and 4-point curves using a linear analysis for both.

The 3-point curve showed a numerical increase in precision between Phase 1 and 2. This is attributed to the control of

access by personnel into the rooms in which testing was preformed. No significant difference was found between the Phase 1 and 2 data to support this claim but it is believed, by looking at the range of differences for each phase, that the room control played a factor in the reduction in precision from Phase 2 to 1.

The bias between the different mixtures was evaluated by grouping the Type C and IC mixes together and the Type B and IB together to determine if there was a difference between precision depending on the type of mixtures. As the results in Table 8 show, there was no constant variation between the two groups of data. The Special Type Mixtures were also separated and analyzed to determine if they would produce a difference. They showed no statistical difference in precision from the combined precision of all the mixtures.

The evaluation of precision, shown in Table 8, did not show a statistical difference in precision by deleting the curves with a fit coefficient of less than 0.995. The percent error of the curve equations that were below the 0.995 value were the equivalent to those above and were well below what is acceptable for an equation fit analysis. The curve data for this phase is in Appendix D and the data used to develop the curves is in Appendix E.

TABLE 8
PHASE 1&2 CURVE PRECISIONS

4-POINT CURVE

		INDEX OF PRECISION			
		TROXLER		CPN	
PHASE	DATA USED	95%	99%	95%	99%
1	ALL	.16	.24	.20	.29
2	ALL	.15	.22	.11	.17
1&2	ALL	.15	.23	.16	.24
1	TYPE C	.10	.15	.17	.25
2	TYPE C	.12	.18	.11	.17
1&2	TYPE C	.11	.16	.15	.22
1	TYPE B	.20	.31	.19	.28
2	TYPE B	.18	.28	.11	.17
1&2	TYPE B	.20	.30	.19	.28
1	COEF OF FIT >.995	.16	.24	.25	.37
2	COEF OF FIT >.995	.14	.22	.12	.18
1&2	COEF OF FIT >.995	.15	.23	.19	.28
2	SPECIAL	.11	.16	.12	.18

3-POINT CURVE

		INDEX OF PRECISION			
		TROXLER		CPN	
PHASE	DATA USED	95%	99%	95%	99%
1	ALL	.18	.27	.17	.26
2	ALL	.12	.19	.11	.16
1&2	ALL	.16	.24	.15	.22
1	TYPE C	.12	.18	.19	.28
2	TYPE C	.12	.18	.06	.09
1&2	TYPE C	.12	.18	.16	.23
1	TYPE B	.23	.34	.15	.23
2	TYPE B	.14	.20	.13	.19
1&2	TYPE B	.20	.30	.14	.21
1	COEF OF FIT >.995	.18	.27	.18	.28
2	COEF OF FIT >.995	.13	.19	.11	.17
1&2	COEF OF FIT >.995	.16	.24	.16	.24
2	SPECIAL	.11	.16	.13	.19

4-point curves consist of points 3.6,4.4,5.2,6.0.
3-point curves consist of points 3.6,4.4,5.2.

Moisture Effect Analysis

The presence of moisture in laboratory check samples was non-existent. In the field, the presence of moisture could be a variable. The gauges are not capable of determining the Neutrons that are thermalized by Hydrogen in water from those thermalized by the Hydrogen in asphalt cement. Aggregate samples were saturated with water and heated until the desired moisture content was obtained. The moisture contents ranged from 0.02% to 0.35%. It was observed that the samples with moisture contents above the 0.2% moisture content level were unstable in weight. The heated aggregate was continually driving off the moisture. The weight of the aggregate was taken as quickly as possible and the asphalt cement added so mixing could begin. The addition of the asphalt cement also drove off moisture as evidenced by the bubbling of the sample after the asphalt cement was added.

After the samples were mixed and placed into the testing pans, a weight into and out of each gauge was taken to determine the average moisture content of the samples while being counted. After mixing, there was little loss of moisture during the testing. The samples were then dried to a constant weight to determine the actual amount of moisture in the sample during testing. This percent moisture was used to correct the asphalt content given by the gauges equation to compare to what was calculated for the sample. Table 9 shows the index of precisions determined from these samples.

TABLE 9
MOISTURE

CURVE	Index of Precision TROXLER 95%	TROXLER 99%	CPN 95%	CPN 99%
ALL MOISTURE SAMPLES MAXIMUM 0.35%				
3-POINT	0.25	0.38	0.19	0.28
4-POINT	0.23	0.34	0.16	0.24
MOISTURE SAMPLES MOISTURE BELOW 0.20%				
3-POINT	0.24	0.36	0.20	0.30
4-POINT	0.16	0.24	0.16	0.23

The results of testing with moisture present in the sample should not be considered accurate. The weights determined for the calculation of the asphalt content were not accurate due to the loss of weight by of moisture evaporation.

The moisture content of a field sample should be below a 0.10%. This conclusion is based on the experiences during the study with mixing samples with moisture present. Low moisture content will minimize the effects the moisture will have on the gauges' ability to precisely determine the asphalt content of the sample. The direct subtraction of the percent moisture content from the gauge derived asphalt content should be the correction procedure used to correct for the presence of moisture in a sample. A separate test

procedure to determine moisture content will have to be used.

Gradation Change Effects

The effect of changing the sample gradation from what the job mix formula specified was evaluated. Phase 1 aggregates were used with the curve point combinations that were specified in Phase 2. The gradations were changed to reflect possible gradations that could be experienced in the field but still within the specification limits. The gradation changes are shown Appendix F and the gauge results are shown in Table 10. The results proved that a change in the gradation would still yield asphalt content results within the precision the gauges had exhibited with gradations at the specified job mix formula. This result is due to the fact that the aggregates used were not high in Hydrogen content which would reduce the effects of the gradation changes.

TABLE 10
CHANGED GRADATION RESULTS

4-POINT CURVE(3.6,4.4,5.2,6.0)

STUDY IDENT NO.	MIX NO.	CALCULATED % ASPHALT	% ASPHALT TROXLER	% ASPHALT CPN
11.14	19	3.97	4.03	4.00
	20	3.99	4.15	4.13
11.24	19	4.00	3.94	3.81
	20	4.00	4.07	3.93
	21	4.01	4.04	3.85
11.15	19	4.00	4.13	4.03
	20	4.00	4.14	4.10
	21	3.98	4.12	4.07
11.25	20	4.00	4.03	3.98
	21	4.04	4.01	4.04
	22	3.99	3.95	3.87
INDEX OF PRECISION				
95%			0.13	0.15
99%			0.20	0.22

3-POINT CURVE(3.6,4.4,5.2)

STUDY IDENT NO.	MIX NO.	CALCULATED % ASPHALT	% ASPHALT TROXLER	% ASPHALT CPN
11.14	19	3.97	4.02	4.00
	20	3.99	4.12	4.12
11.24	19	4.00	3.93	3.84
	20	4.00	4.04	3.95
	21	4.01	4.02	3.87
11.15	19	4.00	4.11	4.03
	20	4.00	4.12	4.10
	21	3.98	4.10	4.07
11.25	20	4.00	4.03	3.88
	21	4.04	4.02	4.03
	22	3.99	3.95	3.84
INDEX OF PRECISION				
95%			0.11	0.15
99%			0.17	0.22

Comparison to Current Test Method
for Asphalt Content Determination

The results of Phase 2 further exhibited the precision that was available from the gauges. Using this phase's data, the gauges approached the 0.10% precision which was the goal from the beginning. The intent of this was to obtain the precision that was believed to be obtained from the ASSHTO T-164 "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures", Method A, and significantly better than the 0.52% stated as the single operator precision of T-164. During the study, samples were randomly selected to have the asphalt content determined by the extraction method. Table 11 shows the precision comparison of the calculated versus the extracted values and the calculated and extracted values versus the asphalt content determined by the gauges with the 3-point and 4-point curves. The data used to determine the index of precision is shown in Appendix G. The curve derived results of percent asphalt content were numerically more precise than the extracted content in comparison to the calculated amount of asphalt in the mixtures. It was felt from the beginning that the gauges were capable of determining the asphalt content at least as accurately as the extraction test.

TABLE 11
EXTRACTED AND CALCULATED

COMPARISON	INDEX OF PRECISION TROXLER 95%	TROXLER 99%	CPN 95%	CPN 99%
ALL DATA				
CALCULATED VS 3 POINT	0.13	0.20	0.16	0.23
EXTRACTED VS 3 POINT	0.28	0.42	0.20	0.30
CALCULATED VS 4 POINT	0.13	0.19	0.15	0.22
EXTRACTED VS 4 POINT	0.28	0.42	0.22	0.32

Calculated Vs Extracted 0.24 at 95% and 0.36 at 99%.

Laboratory to Field Correlation

To use the gauges in the field a calibration must be made for each mixture to be tested. The development of calibration curves would have to be performed in a Central Laboratory to maximize quality control in the making of the calibrations, since a single group of technicians would be involved in the calibration process. The Troxler gauge has a built-in ability to correlate a calibration from one gauge to another. This is done by counting a minimum of 5 known asphalt content samples in the calibrating gauge and then counting the same samples in the gauge to be used in the field. The counts derived by the calibrating gauge are also entered into the field gauge and a correlation is internally developed. Once this correlation is done the variables generated by the calibrating gauge can be entered into the

field gauge and the correlation equation makes the curve variables useful to the field gauge.

This was done between two Troxler, model 3241-C, gauges to examine the process. A calibration was transferred and check samples were tested against the curve transferred. The results were as accurate as on the calibrating gauge. This process is not built into the CPN but is a process that can be done externally. The external type of correlation is done by the Iowa Department of Transportation with their Troxler, model 3241-B gauges which do not have the internal transfer capability.

A correlation with both the Troxler and CPN gauges must be done at least yearly to make sure the transferred calibrations are applied correctly by the field gauges. Correlation would also serve as a check of the gauge performance on an annual basis. This correlation is between gauges of the same model and manufacturer. A correlation between different models and manufacturers was not explored, but it is strongly suspected it is not possible.

Phase 2 showed that the gauges were able to determine the asphalt content more accurately than the current extraction method. The effects of moisture, gradation, and environment were established. Moisture could be corrected for, and the gradation, when within the specification gradation limits,

had no effect on the gauges ability to determine the asphalt content. The environment in which the gauges are operated has to remain constant during the test. This is a condition that can be controlled.

The question of whether to use 3-points or 4-points in the calibration process was answered in that the 3-point curves were as precise as the 4-point curves. The time and equipment needed to develop a 4-point curve would not be warranted. The quadratic equation analyses did not add to the precision of the Troxler gauge so the use of a quadratic analysis would not be necessary.

The use of a linear analysis with a 3-point curve will make it possible to use either gauge to determine the asphalt content of bituminous mixtures.

CONCLUSIONS

The objective of this study was to determine if the asphalt content of bituminous mixtures could be determined with a Nuclear Asphalt Content Gauge to at least the same accuracy as test method AASHTO T-164, Method A,"Quantitative Extraction of Bitumen from Bituminous Paving Mixtures". While determining the precision of the gauges it was necessary to establish some operational procedures for use of the gauges. The following are conclusions drawn from this study.

After testing several combinations of asphalt content points, it was determined a 3-point calibration of the gauges was satisfactory. The 3-point calibration produced an index of precision of ±0.15% asphalt content 95% of the time for the CPN gauge and ±0.16% asphalt content 95% of the time for the Troxler gauge. The three asphalt content points for the calibration curves used were 0.8% above, 0.8% below, and at the approved job mix formula asphalt content.

The quadratic analysis was not significantly better than the linear analysis used by both gauges for a 3-point calibration. This meant the use of the quadratic equation analysis provided by the Troxler gauge was not necessary. The time needed to produce a calibration would be kept at a minimum by using a 3-point calibration.

To produce a 3-point calibration, 4 samples would be batched with 1 used as a butter and the other 3 mixed at different asphalt contents to use in the calibration. Calibration should be done after a mix is designed and a approved job mix formula established. Calibration before the mix design, would not necessarily allow for the proper range of asphalt contents. The job mix gradation would also not be known.

The number of asphalt cement content points and the spread of these points in a calibration is dependent on the allowable deviation of asphalt cement content from the job mix formula.

All calibrations should be done by one group of technicians using the same set of equipment to insure consistency. This would also eliminate the need to equip several laboratories. The transfer of a calibration from a laboratory gauge to a field gauge would be possible by the use of a correlation equation established annually for each field gauge.

The accounting for moisture in a sample would have to be done as a separate test procedure. Once the moisture content of a sample is established it can be used to adjust the asphalt content as determined by the gauge. The moisture content should remain constant from day-to-day if all plant processes and aggregate conditions remain constant. The moisture content determined the previous day can be applied

as an intermediate correction until the actual content has been determined.

The environment in which the gauges are operated must be controlled and must remain constant during testing. Changes in the environment that increases or decreases the presence of Hydrogen or Neutron bearing material must be controlled. Otherwise the precision of the test may be affected.

The precision is more than adequate to replace current extraction procedures if asphalt content is the only unknown to be determined. On site determination of the asphalt content of bituminous mixtures by use of a nuclear gauge would yield the asphalt cement content of a bituminous mixture without the use of or disposition of chemicals of a hazardous nature. If environment, moisture, and gradation are accounted for and the calibrations are preformed as required for each mixture, the use of the nuclear gauge in lieu of ASSHTO T-164, Method A, is recommended.

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APPENDIX A

BACKGROUND DATA

DATE	CPN COUNTS	TROXLER COUNTS
NOV. 14	6286	2304
NOV. 15	6353	2287
NOV. 17	6282	2295
NOV. 18	6258	2287
NOV. 21	6286	2282
NOV. 22	6208	2293
NOV. 23	6298	2289
NOV. 28	6254	2285
NOV. 29	6278	2285
DEC. 1	6335	2279
DEC. 5	6342	2279
DEC. 6	6315	2301
DEC. 7	6262	2302
DEC. 8	6231	2297
DEC. 9	6259	2303
DEC. 13	6254	2289
DEC. 14	6255	2284
DEC. 15	6277	2303
DEC. 16	6221	2307
DEC. 19	6313	2278
DEC. 20	6303	2304
DEC. 21	6324	2319
DEC. 22	6328	2299
DEC. 27	6314	2275
DEC. 28	6278	2284
DEC. 29	6197	2317
DEC. 30	6307	2294
JAN. 3	6284	2288
JAN. 4	6262	2301
JAN. 6	6266	2288
AVERAGE	6281	2293
DEVIATION 68%	37	11
DEVIATION 95%	73	21
DEVIATION 99%	96	28

APPENDIX B

CPN DATA PHASE 1

STUDY IDENT	11.14			11.15			11.24			11.25		
MIX NO.	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT
4	0.00	6012	6286	0.00	6103	6342	0.00	5873	6322	0.00	5921	6231
2	3.73	9664	6252	3.55	9342	6342	3.57	9434	6322	3.58	9480	6231
3				3.80	9713	6315				3.77	9687	6231
4	3.99	10187	6286	4.00	9920	6342	3.98	9745	6322	4.00	10040	6231
5				4.14	10058	6262	4.16	9990	6325	4.13	10137	6231
6				4.22	10188	6262	4.20	10116	6325	4.22	10163	6259
7	4.41	10517	6286	4.36	10430	6342	4.33	10349	6322	4.31	10375	6259
8				4.63	10812	6262				4.40	10498	6231
9				4.73	10698	6262	4.70	10568	6325	4.61	10690	6231
10	4.96	11315	6252	4.83	10829	6315	4.82	10636	6322	4.67	10832	6259
11	4.94	11356	6286	5.01	11249	6342	5.02	11192	6322	4.81	10969	6231
12				5.11	11520	6262	5.14	11385	6325	5.00	11272	6231
13	5.17	11825	6252	5.23	11324	6315	5.15	11550	6322	5.11	11493	6259
14				5.42	11701	6262	5.45	11713	6325	5.20	11492	6259
15	5.46	12011	6252	5.63	12235	6315	5.60	11776	6278	5.38	11829	6259
16				5.81	12587	6315	5.84	12354	6325	5.60	12313	6259
17	6.01	13198	6286	5.99	12317	6342	5.97	12240	6278	5.79	12466	6259
18	7.09	15100	6286	6.99	14681	6342	6.97	14485	6325	6.00	12795	6231
19	3.97	10027	6254	4.00	9874	6254	4.00	9698	6254	6.99	14786	6259
20	3.99	10216	6254	4.00	9956	6254	4.00	9845	6254	4.00	9974	6254
21				3.98	9916	6254	4.01	9742	6254	4.04	10056	6254
22										3.99	9829	6254

TROXLER DATA PHASE 1

STUDY IDENT	11.14			11.15			11.24			11.25		
MIX NO.	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT	% AC	COUNT	BKG COUNT
4	0.00	1838	2282	0.00	1955	2279	0.00	1930	2285	0.00	1944	2297
2	3.73	2671	2293	3.55	2623	2279	3.57	2618	2285	3.58	2654	2297
3	3.75	2720	2293	3.80	2672	2301	3.83	2661	2285	3.77	2718	2297
4	3.99	2711	2282	4.00	2742	2279	3.98	2691	2285	4.00	2782	2297
5				4.14	2768	2302	4.16	2773	2279	4.13	2810	2303
6	4.30	2845	2289	4.22	2813	2302	4.20	2776	2279	4.22	2830	2303
7	4.41	2879	2293	4.36	2819	2279	4.33	2817	2285	4.31	2852	2303
8	4.64	2928	2289	4.63	2900	2302	4.59	2850	2285	4.40	2889	2297
9				4.73	2935	2302	4.70	2930	2279	4.61	2950	2297
10	4.96	3055	2289	4.83	2916	2301	4.82	2935	2285	4.67	2937	2303
11	4.94	2985	2282	5.01	2988	2279	5.02	2945	2285	4.81	2991	2297
12				5.11	3064	2302	5.14	3034	2279	5.00	3065	2297
13	5.17	3123	2293	5.23	3052	2301	5.15	3027	2285	5.11	3059	2303
14	5.45	3224	2289	5.42	3092	2302	5.45	3089	2285	5.20	3090	2303
15	5.46	3191	2293	5.63	3156	2301	5.60	3147	2285	5.38	3135	2303
16	5.83	3308	2289	5.81	3205	2301	5.84	3210	2285	5.60	3196	2303
17	6.01	3346	2282	5.99	3253	2279	5.97	3282	2285	5.79	3256	2303
18	7.09	3752	2282	6.99	3619	2279	6.97	3583	2279	6.00	3316	2297
19	3.97	2758	2289	4.00	2766	2289	4.00	2712	2289	6.99	3692	2297
20	3.99	2797	2289	4.00	2768	2289	4.00	2744	2289	4.00	2778	2289
21				3.98	2763	2289	4.01	2736	2289	4.04	2776	2289
22										3.99	2758	2289

APPENDIX C

CPN CURVE DATA PHASE 1

CURVE NO.	FIT COEFF	VARIABLES A	B	C	% ERROR
C-14-1	1.000	1335.78	4757.24	6286	
C-14-2	1.000	1617.09	3634.80	6286	
C-14-3	.994	1543.89	3858.38	6286	
C-14-4	.996	1630.75	3453.86	6286	
C-14-5	.994	1308.64	4804.56	6252	
C-14-6	.986	1441.11	4252.16	6252	
C-14-7	.989	1402.04	4414.39	6252	
C-14-8	.988	1498.03	3998.03	6252	
C-14-9	.991	1602.20	3556.39	6286	
C-14-11	.997	1063.98	5984.53	6286	
C-14-12	.982	1269.60	5710.60	6286	
C-14-13	.986	1154.23	5852.17	6286	
C-14-14	.975	1250.58	5640.51	6286	
C-14-15	.995	1045.92	5957.61	6286	
C-14-16	.988	1085.93	5857.52	6252	
C-14-17	.988	1102.22	5825.06	6252	
C-14-18	.979	1154.90	5726.24	6286	
C-14-19	.886	1691.73	3080.81	6286	
C-14-21	.995	1561.89	3740.04	6252	1.123
C-14-22	.988	1505.86	3976.32	6252	1.543
C-24-1	1.000	1391.34	4207.44	6322	
C-24-2	1.000	1584.28	3439.54	6322	
C-24-3	.997	1277.69	4697.96	6322	
C-24-4	.979	1542.75	3463.72	6322	
C-24-5	.960	1014.67	5804.71	6322	
C-24-6	.945	1267.31	4804.64	6322	
C-24-7	.966	1238.11	1924.60	6322	
C-24-8	.978	1229.63	4960.53	6322	
C-24-9	.969	1438.39	4025.41	6322	
C-24-11	.995	1035.47	5830.23	6322	
C-24-12	.980	1221.06	5576.45	6322	
C-24-13	.995	1064.80	5788.46	6322	
C-24-14	.975	1178.08	5545.77	6322	
C-24-15	.997	999.25	5869.88	6322	
C-24-16	.987	1045.22	5791.45	6322	
C-24-17	.989	1059.36	5761.05	6322	
C-24-18	.989	1073.90	5725.13	6322	
C-24-19	.877	1615.96	3090.40	6322	
C-24-21	.991	1215.27	5125.59	6322	1.285
C-24-22	.996	1340.87	4611.53	6322	.804

CPN CURVE DATA PHASE 1

CURVE NO.	FIT COEFF	VARIABLES A	B	C	% ERROR
C-15-1	1.000	1315.85	4656.58	6342	
C-15-2	1.000	1592.31	3550.77	6342	
C-15-3	.990	1205.09	5136.54	6342	
C-15-4	.968	1543.03	3558.96	6342	
C-15-5	.991	1198.95	5119.36	6342	
C-15-6	.995	1180.44	5192.90	6342	
C-15-7	.981	1324.26	4601.89	6342	
C-15-8	.983	1269.04	4835.82	6342	
C-15-9	.971	1479.27	3891.27	6342	
C-15-11	.996	1006.45	6067.97	6342	
C-15-12	.978	1212.24	5793.82	6342	
C-15-13	.996	1030.26	6033.76	6342	
C-15-14	.968	1158.91	5757.11	6342	
C-15-15	.996	977.868	6056.29	6342	
C-15-16	.995	993.726	6028.30	6342	
C-15-17	.984	1044.65	5918.77	6342	
C-15-18	.986	1054.80	5893.74	6342	
C-15-19	.870	1615.42	3170.79	6342	
C-15-21	.998	1201.37	5117.43	6342	.639
C-15-22	.995	1194.13	5144.02	6342	.939
C-25-1	1.000	1232.00	5112.00	6231	
C-25-2	1.000	1577.92	3728.29	6231	
C-25-3	.996	1377.50	4481.50	6231	
C-25-4	.988	1572.02	3574.04	6231	
C-25-5	.998	1204.53	5190.73	6231	
C-25-6	.999	1209.25	5171.87	6231	
C-25-7	.988	1329.44	4676.09	6231	
C-25-8	.991	1367.18	4515.32	6231	
C-25-9	.986	1517.85	3836.79	6231	
C-25-11	1.000	1232.00	5112.00	6231	
C-25-12	.985	1251.39	5655.38	6231	
C-25-13	.993	1117.35	5816.94	6231	
C-25-14	.979	1217.90	5600.85	6231	
C-25-15	.998	1040.30	5888.27	6231	
C-25-16	.997	1054.66	5863.22	6231	
C-25-17	.990	1095.44	5776.24	6231	
C-25-18	.987	1128.00	5695.28	6231	
C-25-19	.884	1660.38	3083.15	6231	
C-25-21	.993	1353.31	4570.08	6231	1.222
C-25-22	.999	1224.76	5099.86	6231	.107

TROXLER CURVE DATA PHASE 1

CURVE NO.	FIT COEFF	VARIABLES A1	A2	A3	% ERROR
T-15-1	1.000	-7.257807	4.105692		
T-15-2	1.000	-5.348437	3.409350		
T-15-3	1.000	-6.653356	3.891803		
T-15-4	1.000	-17.537976	11.202070	-12.215838	
T-15-5	1.000	42.530593	-32.585071	67.574995	
T-15-6	.994	-16.439587	10.483057	-10.958719	
T-15-7	.997	-17.715863	11.399866	-12.601939	
T-15-8	.998	-19.557156	12.700178	-14.890843	
T-15-9	.999	-18.016150	11.637396	-13.066949	
T-15-10	.996	-9.604502	5.879577	-3.244226	
T-15-11	.999	-9.565869	4.906650		
T-15-12	.993	-7.939417	4.185696		
T-15-13	1.000	-14.804749	9.351686	-9.098567	
T-15-14	1.000	-15.505556	9.936071	-10.267068	
T-15-15	.999	-12.925240	7.652897	-5.319213	
T-15-16	.999	-15.032422	9.489079	-9.207507	
T-15-17	1.000	-15.334372	9.749662	-9.753123	
T-15-18	1.000	-15.813502	10.157599	-10.594518	
T-15-19	1.000	-16.195727	10.473232	-11.225050	
T-15-20	.999	-15.684164	10.062436	-10.413677	
T-15-21	1.000	-14.342765	9.175055	-8.984284	2.452
T-15-22	1.000	-7.276643	4.127706		.018
T-25-1	1.000	-5.830389	3.533569		
T-25-2	1.000	-5.140856	3.285714		
T-25-3	.999	-6.425774	3.740841		
T-25-4	.999	-14.451411	9.105236	-8.920436	
T-25-5	1.000	7.259403	-5.859221	16.852456	
T-25-6	1.000	5.523828	-4.615764	14.629163	
T-25-7	1.000	0.124765	-0.799611	7.902697	
T-25-8	.999	-6.547139	3.847513	-0.161910	
T-25-9	.999	-13.861846	8.825119	-8.588285	
T-25-10	.999	-1.872339	0.632936	5.336707	
T-25-11	.998	-8.768801	4.531691		
T-25-12	.994	-7.528866	3.988667		
T-25-13	1.000	-12.877933	7.962928	-6.873512	
T-25-14	1.000	-13.683234	8.631388	-8.197205	
T-25-15	1.000	-16.067127	10.674761	-12.389338	
T-25-16	1.000	-14.637455	9.433787	-9.780726	
T-25-17	1.000	-13.839781	8.749134	-8.360729	
T-25-18	1.000	-13.706032	8.635909	-8.129554	
T-25-19	1.000	-14.176838	9.022944	-8.895675	
T-25-20	1.000	-13.172720	8.193828	-7.274289	
T-25-21	.999	-6.600318	3.943598	-0.422631	2.433
T-25-22	.999	-6.822750	3.908497		1.213

TROXLER CURVE DATA PHASE 1

CURVE NO.	FIT COEFF	VARIABLES A1	A2	A3	% ERROR
T-14-1	1.000	-5.409453	3.467153		
T-14-2	1.000	-4.083103	2.977906		
T-14-3	.999	-4.574075	3.169899		
T-14-4	1.000	-9.619287	6.506515	-5.474496	
T-14-5	.998	-81.074458	56.638563	-93.210435	
T-14-6	.993	-53.462688	37.170170	-58.972538	
T-14-7	.998	-20.552390	14.237829	-19.163129	
T-14-8	.992	-3.069571	2.199350	1.504761	
T-14-9	.996	-6.125430	4.278872	-2.010537	
T-14-10	.994	-9.816842	6.553126	-5.557145	
T-14-11	.999	-8.000138	4.370907		
T-14-12	.992	-6.492618	3.681226		
T-14-13	1.000	-12.937079	8.717471	-9.132139	
T-14-14	1.000	-12.292228	8.163870	-8.007490	
T-14-15	.999	-15.469018	10.993628	-14.037779	
T-14-16	.999	-15.323289	10.861716	-13.750693	
T-14-17	.999	-14.571614	10.189089	-12.306504	
T-14-18	.998	-13.288156	9.066652	-9.958868	
T-14-19	.998	-11.960774	7.945234	-7.697169	
T-14-20	.999	-12.330221	8.212937	-8.288425	
T-14-21	1.000	-0.362000	0.124879	5.316622	.701
T-14-22	1.000	-4.767721	3.183808		.319
T-24-1	1.000	-7.038267	4.094488		
T-24-2	1.000	-4.980010	3.329621		
T-24-3	.994	-4.933055	3.338099		
T-24-4	.999	-9.891849	6.584404	-5.263709	
T-24-5	.994	-16.179734	10.936758	-12.907420	
T-24-6	.997	-10.728098	6.975449	-5.722399	
T-24-7	.998	-7.867198	4.924784	-2.056963	
T-24-8	.999	-12.297445	8.054018	-7.562818	
T-24-9	.999	-10.378085	6.727456	-5.282894	
T-24-10	.998	-9.066227	5.739835	-3.412577	
T-24-11	.999	-9.638522	5.011309		
T-24-12	.992	-7.776701	4.175408		
T-24-13	1.000	-17.618455	11.890586	-14.318949	
T-24-14	1.000	-15.838665	10.394323	-11.302248	
T-24-15	1.000	-17.491800	11.882288	-14.606860	
T-24-16	1.000	-16.846684	11.314514	-13.393545	
T-24-17	1.000	-15.983956	10.565100	-11.816383	
T-24-18	1.000	-15.938128	10.525910	-11.735332	
T-24-19	1.000	-14.802587	9.582803	-9.843786	
T-24-20	.999	-15.771682	10.363612	-11.335042	
T-24-21	1.000	-12.480485	8.113653	-7.587009	2.398
T-24-22	1.000	-6.547546	3.863465		.164

APPENDIX D

CPN CURVE DATA PHASE 2

CURVE NO.	FIT COEFF	VARIABLES A	B	C	% ERROR
C-10-1	.999	1444.94	4634.88	6277	.496
C-10-2	1.000	1390.19	4912.22	6277	.047
C-20-1	.999	1540.15	4355.78	6255	.318
C-20-2	1.000	1503.25	4581.39	6255	.062
C-11-1	.999	1365.55	4679.85	6317	.358
C-11-2	.998	1338.55	4809.71	6317	.450
C-21-1	.999	1496.95	4275.61	6324	.291
C-21-2	.999	1469.14	4394.43	6324	.211
C-13-1	.999	1721.81	3522.26	6328	.568
C-13-2	.998	1678.84	3699.75	6328	.635
C-23-1	.992	1559.04	3984.97	6314	1.478
C-23-2	.998	1394.79	4668.16	6314	.391
C-16-1	.999	1457.15	4480.54	6197	.439
C-16-2	1.000	1504.87	4283.55	6197	.090
C-26-1	.994	1441.02	4398.54	6197	1.155
C-26-2	.986	1428.83	4449.83	6197	1.713
C-17-1	.991	1404.74	4235.75	6261	1.514
C-17-2	.983	1467.57	3976.99	6261	2.069
C-27-1	.998	1728.31	4241.84	6932	.745
C-27-2	.996	1668.91	4487.71	6932	.886
C-30-1	.996	1720.92	4337.15	6266	1.061
C-30-2	1.000	1853.26	3790.35	6266	.120
C-40-1	.999	1790.97	3800.31	6266	.437
C-40-2	1.000	1738.43	4017.56	6266	.062
C-50-1	.999	1823.87	4072.88	6284	.425
C-50-2	.998	1798.54	4177.38	6284	.557

TROXLER CURVE DATA PHASE 2

CURVE NO.	FIT COEFF	VARIABLES A1	A2	A3	% ERROR
T-10-1	1.000	-6.928938	4.188053	-1.031023	.958
T-10-2	1.000	-6.096117	3.600954		.186
T-20-1	1.000	-9.501518	5.914844	-4.111210	1.631
T-20-2	1.000	-5.885236	3.471364		.496
T-11-1	.998	-7.427992	4.303314	-0.851197	2.288
T-11-2	.996	-6.977553	3.901767		2.121
T-21-1	1.000	-9.567799	6.067749	-4.376791	1.751
T-21-2	1.000	-5.879374	3.521540		.196
T-13-1	.998	-5.702333	3.711847	-1.028089	2.372
T-13-2	.996	-4.510163	3.000392		2.262
T-23-1	1.000	-18.675676	12.158578	-14.478219	4.091
T-23-2	.999	-6.403554	3.713248		1.363
T-16-1	.998	2.050879	-1.827292	8.800981	2.346
T-16-2	.999	-5.389666	3.299888		.978
T-26-1	.998	-18.266602	11.850597	-13.922576	4.330
T-26-2	.991	-6.013440	3.571220		3.482
T-17-1	.994	-10.213118	6.639689	-5.187103	4.500
T-17-2	.985	-5.376324	3.449779		4.558
T-27-1	1.000	-9.357836	5.699945	-3.746166	1.614
T-27-2	1.000	-5.931867	3.429700		.725
T-30-1	1.000	3.429601	-2.416504	8.868176	1.661
T-30-2	1.000	-4.771220	2.990168		.965
T-40-1	1.000	-6.419486	4.108267	-1.735215	1.510
T-40-2	1.000	-4.951123	3.096398		.670
T-50-1	1.000	-8.597097	5.191336	-3.256500	1.714
T-50-2	.999	-5.373925	3.136962		.954

APPENDIX E

TROXLER DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.10	1	3.59		3.59	2689	2303
	2	4.43		4.43	2925	2303
	3	5.20		5.20	3136	2303
	4	5.99		5.99	3364	2303
	5	4.00		4.00	2855	2303
	6	4.81		4.81	3049	2303
	7	5.62		5.62	3295	2303
	5A	3.98	.36	4.34	2979	2303
	6A	4.79	.10	4.89	3057	2303
	7A	5.56	.62	6.18	3529	2303
11.20	1	3.61		3.61	2738	2284
	2	4.38		4.38	2952	2284
	3	5.18		5.18	3190	2284
	4	6.00		6.00	3446	2284
	5	5.57		5.57	3259	2284
	6	4.84		4.84	3106	2284
	7	4.00		4.00	2865	2284
11.11	1	3.62		3.62	2708	2278
	2	4.41		4.41	2938	2278
	3	5.17		5.17	3102	2278
	4	6.02		6.02	3351	2278
	5	5.61		5.61	3201	2278
	6	4.79		4.79	3032	2278
	7	4.01		4.01	2765	2278
	5A	5.66	.26	5.92	3337	2278
11.21	1	3.59		3.59	2690	2319
	2	4.40		4.40	2917	2319
	3	5.21		5.21	3150	2319
	4	6.01		6.01	3403	2319
	5	5.61		5.61	3285	2319
	6	4.81		4.81	3084	2319
	7	4.00		4.00	2839	2319
	5A	5.58	.04	5.62	3340	2284
	5B	5.61	.14	5.75	3340	2284

TROXLER DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.13	1	3.59		3.59	2715	2299
	2	4.41		4.41	2946	2299
	3	5.20		5.20	3248	2299
	4	6.00		6.00	3481	2299
	5	5.61		5.61	3354	2299
	6	4.79		4.79	3092	2299
	7	3.97		3.97	2824	2299
	5A	5.61	.04	5.65	3314	2284
	5B	5.61	.11	5.72	3379	2284
11.23	1	3.60		3.60	2701	2275
	2	4.41		4.41	2899	2275
	3	5.17		5.17	3123	2275
	4	5.96		5.96	3414	2275
	5	5.57		5.57	3245	2275
	6	4.81		4.81	2998	2275
	7	4.00		4.00	2779	2275
	5A	5.49	.10	5.59	3285	2284
	5B	5.58	.06	5.64	3268	2284
11.16	1	3.60		3.60	2730	2317
	2	4.39		4.39	2953	2317
	3	5.21		5.21	3217	2317
	4	5.99		5.99	3387	2317
	5	5.62		5.62	3229	2317
	6	4.80		4.80	3059	2317
	7	4.00		4.00	2836	2317
	5A	5.51	.13	5.64	3284	2294
	5B	5.60	.14	5.74	3373	2294
11.26	1	3.60		3.60	2713	2275
	2	4.41		4.41	2884	2275
	3	5.18		5.18	3148	2275
	4	5.99		5.99	3417	2275
	5	5.62		5.62	3264	2275
	6	4.80		4.80	3003	2275
	7	4.00		4.00	2809	2275
	5A	5.61	.23	5.84	3364	2294
	5B	5.60	.08	5.68	3295	2294

TROXLER DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.17	1	3.57		3.57	2623	2301
	2	4.41		4.41	2790	2301
	3	5.19		5.19	3080	2301
	4	6.00		6.00	3268	2301
	5	5.60		5.60	3221	2301
	6	4.77		4.77	2948	2301
	7	4.03		4.03	2722	2301
	5A	5.55		5.55	3213	2299
	5B	5.61		5.61	3244	2299
11.27	1	3.61		3.61	2786	2289
	2	4.39		4.39	3002	2289
	3	5.13		5.13	3229	2289
	4	6.00		6.00	3498	2289
	5	5.62		5.62	3350	2289
	6	4.78		4.78	3134	2289
	7	3.98		3.98	2889	2289
	5A	5.55		5.55	3353	2299
	5B	5.53	.07	5.60	3412	2299
11.30	1	3.60		3.60	2795	2288
	2	4.38		4.38	3070	2288
	3	5.18		5.18	3323	2288
	4	6.02		6.02	3547	2288
	5	5.58		5.58	3426	2288
	6	4.82		4.82	3166	2288
	7	3.98		3.98	2886	2288
	5A	5.52	.23	5.75	3577	2299
	5B	5.53	.37	5.90	3525	2299

TROXLER DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.40	1	3.60		3.60	2758	2288
	2	4.41		4.41	3031	2288
	3	5.19		5.19	3271	2288
	4	5.99		5.99	3557	2288
	5	5.61		5.61	3398	2288
	6	4.79		4.79	3169	2288
	7	4.07		4.07	2910	2288
	5A	5.58		5.58	3441	2299
	5B	5.68		5.68	3475	2299
11.50	1	3.58		3.58	2860	2288
	2	4.41		4.41	3108	2288
	3	5.20		5.20	3376	2288
	4	6.01		6.01	3647	2288
	5	5.57		5.57	3482	2288
	6	4.80		4.80	3238	2288
	7	3.98		3.98	2983	2288
	5A	5.58	.02	5.60	3529	2299
	5B	5.60		5.60	3494	2299

CPN DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.10	1	3.59		3.59	9850	6277
	2	4.43		4.43	11024	6277
	3	5.20		5.20	12088	6277
	4	5.99		5.99	13335	6277
	5	4.00		4.00	10300	6277
	6	4.81		4.81	11305	6277
	7	5.62		5.62	12735	6277
	5A	3.98	.36	4.34	11189	6303
	6A	4.79	.10	4.89	11579	6303
	7A	5.56	.62	6.18	13993	6303
11.20	1	3.61		3.61	9938	6255
	2	4.38		4.38	11087	6255
	3	5.18		5.18	12298	6255
	4	6.00		6.00	13625	6255
	5	5.57		5.57	12610	6255
	6	4.84		4.84	11740	6255
	7	4.00		4.00	10567	6255
11.11	1	3.62		3.62	9625	6317
	2	4.41		4.41	10741	6317
	3	5.17		5.17	11699	6317
	4	6.02		6.02	12914	6317
	5	5.61		5.61	12474	6317
	6	4.79		4.79	11353	6317
	7	4.01		4.01	10166	6317
	5A	5.66	.26	5.92	12969	6303
11.21	1	3.59		3.59	9674	6324
	2	4.40		4.40	10836	6324
	3	5.21		5.21	12054	6324
	4	6.01		6.01	13295	6324
	5	5.61		5.61	12635	6324
	6	4.81		4.81	11433	6324
	7	4.00		4.00	10238	6324
	5A	5.58	.04	5.62	12740	6278
	5B	5.61	.14	5.75	12853	6278

CPN DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.13	1	3.59		3.59	9755	6328
	2	4.41		4.41	11046	6328
	3	5.20		5.20	12459	6328
	4	6.00		6.00	13888	6328
	5	5.61		5.61	13275	6328
	6	4.79		4.79	11889	6328
	7	3.97		3.97	10349	6328
	5A	5.61	.04	5.65	12944	6278
	5B	5.61	.11	5.72	13062	6278
11.23	1	3.60		3.60	9668	6314
	2	4.41		4.41	10849	6314
	3	5.17		5.17	11857	6314
	4	5.96		5.96	13406	6314
	5	5.57		5.57	12599	6314
	6	4.81		4.81	11282	6314
	7	4.00		4.00	10270	6314
	5A	5.49	.10	5.59	12838	6278
	5B	5.58	.06	5.64	12669	6278
11.16	1	3.60		3.60	9697	6197
	2	4.39		4.39	10898	6197
	3	5.21		5.21	12120	6197
	4	5.99		5.99	13170	6197
	5	5.62		5.62	12536	6197
	6	4.80		4.80	11288	6197
	7	4.00		4.00	10312	6197
	5A	5.51	.13	5.64	12492	6307
	5B	5.60	.14	5.74	12949	6307
11.26	1	3.60		3.60	9666	6197
	2	4.41		4.41	10600	6197
	3	5.18		5.18	11927	6197
	4	5.99		5.99	13040	6197
	5	5.62		5.62	12561	6197
	6	4.80		4.80	11235	6197
	7	4.00		4.00	10193	6197
	5A	5.61	.23	5.84	12911	6307
	5B	5.60	.08	5.68	12655	6307

CPN DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.17	1	3.57		3.57	9301	6262
	2	4.41		4.41	10273	6262
	3	5.19		5.19	11685	6262
	4	6.00		6.00	12613	6262
	5	5.60		5.60	12257	6262
	6	4.77		4.77	10961	6262
	7	4.03		4.03	9760	6262
	5A	5.55		5.55	12180	6245
	5B	5.61		5.61	12308	6245
11.27	1	3.61		3.61	10554	6932
	2	4.39		4.39	11729	6932
	3	5.13		5.13	13093	6932
	4	6.00		6.00	14654	6932
	5	5.62		5.62	13714	6932
	6	4.78		4.78	12522	6932
	7	3.98		3.98	11209	6932
	5A	5.55		5.55	12953	6245
	5B	5.53	.07	5.60	13170	6245
11.30	1	3.60		3.60	10468	6266
	2	4.38		4.38	11896	6266
	3	5.18		5.18	13396	6266
	4	6.02		6.02	14596	6266
	5	5.58		5.58	13932	6266
	6	4.82		4.82	12523	6266
	7	3.98		3.98	10907	6266
	5A	5.52	.23	5.75	14581	6245
	5B	5.53	.37	5.90	14414	6245

CPN DATA PHASE 2

STUDY IDENT NO.	MIX NO.	% AC	% MOIST	TOTAL % MOIST AND AC	COUNTS	BKG COUNTS
11.40	1	3.60		3.60	10273	6266
	2	4.41		4.41	11690	6266
	3	5.19		5.19	13037	6266
	4	5.99		5.99	14570	6266
	5	5.61		5.61	13592	6266
	6	4.79		4.79	12442	6266
	7	4.07		4.07	11166	6266
	5A	5.58		5.58	13707	6245
	5B	5.68		5.68	13783	6245
11.50	1	3.58		3.58	10643	6284
	2	4.41		4.41	12054	6284
	3	5.20		5.20	13558	6284
	4	6.01		6.01	15055	6284
	5	5.57		5.57	14182	6284
	6	4.80		4.80	12916	6284
	7	3.98		3.98	11503	6284
	5A	5.58	.02	5.60	14466	6245
	5B	5.60		5.60	14160	6245

APPENDIX F

CHANGED GRADATION SAMPLES

STUDY IDENT 11.15

MIX NO.	4	19	20	21
SIEVE SIZE	JOB MIX			
1-3/4	9.0	4.0	14.0	9.0
3/4-1/2	16.8	16.8	16.8	21.8
1/2-3/8	10.2	15.2	5.2	5.2
3/8-4	18.8	18.8	18.8	18.8
4-10	10.0	10.0	10.0	10.0
10-40	8.3	8.3	8.3	8.3
40-80	13.1	13.1	13.1	13.1
80-200	5.2	5.2	5.2	5.2
-200	4.6	4.6	4.6	4.6

STUDY IDENT 11.25

MIX NO.	4	20	21	22
SIEVE SIZE	JOB MIX			
1-3/4				
3/4-1/2	.3	.3	5.3	5.3
1/2-3/8	12.9	12.3	7.3	7.9
3/8-4	31.3	29.9	29.9	31.3
4-10	16.4	15.8	15.8	16.4
10-40	9.5	10.2	10.2	9.5
40-80	14.0	15.5	15.5	14.0
80-200	5.7	6.2	6.2	5.7
-200	5.8	5.8	5.8	5.8

CHANGED GRADATION SAMPLES

STUDY IDENT 11.14

MIX NO.	4	19	20
SIEVE SIZE	JOB MIX		
1-3/4	7.7	2.7	12.7
3/4-1/2	22.5	22.5	22.5
1/2-3/8	9.4	14.4	9.4
3/8-4	18.1	18.1	13.2
4-10	8.6	8.6	8.6
10-40	9.6	9.6	9.6
40-80	11.2	11.2	11.2
80-200	4.1	4.1	4.1
-200	4.8	4.8	4.8

STUDY IDENT 11.24

MIX NO.	4	19	20	21
SIEVE SIZE	JOB MIX			
1-3/4				
3/4-1/2	2.2		7.2	7.2
1/2-3/8	12.1	12.1	12.1	7.1
3/8-4	32.4	34.5	32.4	32.4
4-10	15.3	15.3	10.2	15.3
10-40	11.4	11.4	11.4	11.4
40-80	12.5	12.5	12.5	12.5
80-200	4.6	4.6	4.6	4.6
-200	5.5	5.5	5.5	5.5

APPENDIX G

EXTRACTION CHECKS

IDENT NO.	MIX NO.	% ASPHALT CALCULATED	% ASPHALT EXTRACTED	TROXLER % ASPHALT 3 PT	TROXLER % ASPHALT 4 PT	CPN % ASPHALT 3 PT	CPN % ASPHALT 4 PT
FO88-209	11.14.04	3.99	3.88	3.83	3.85	4.04	4.04
FO88-210	11.14.13	5.17	5.07	5.14*	5.18*	5.21*	5.18*
FO88-211	11.14.03	3.75	3.77	3.89	3.91	3.82	3.84
FO88-212	11.24.09	4.70	4.59	4.75	4.76	4.44	4.48
FO88-213	11.24.12	5.14	5.10	5.15	5.13	5.05	5.15
FO88-214	11.15.03	3.80	3.96	3.84	3.85	3.85	3.85
FO88-215	11.25.08	4.40	4.46	4.47*	4.44*	4.41*	4.38*
FO88-216	11.25.07	4.31	4.27	4.35	4.33	4.28	4.27
FO88-217	11.25.14	5.20	5.29	5.28*	5.20*	5.20*	5.09*
FO88-218	11.14.20	3.99	4.03	4.12	4.13	4.14	4.14
FO88-219	11.20.01	3.61	3.38	3.62*	3.61*	3.56*	3.62*
FO88-220	11.20.05	5.57	5.48	5.43	5.41	5.34	5.36
FO88-224	11.10.06	4.81	4.29	4.88	4.88	4.64	4.65
FO88-229	11.21.06	4.81	4.64	4.98	4.98	4.79	4.78
FO88-230	11.13.06	4.79	4.96	4.77	4.79	4.88	4.86
FO88-231	11.23.06	4.81	4.73	4.73	4.76	4.74	4.68
FO88-232	11.16.03	5.21	5.23	5.23*	5.28*	5.21*	5.24*
FO88-233	11.26.02	4.41	4.56	4.29*	4.33*	4.31*	4.30*
FO89-7	11.50.07	3.98	4.24	3.98	3.99	4.07	4.07
FO89-8	11.17.03	4.41	4.39	4.25*	4.27*	4.29*	4.30*

* Point used to make up the curve.

% Asphalt points used to make 3-point curve were 3.6,4.4,5.2.
% Asphalt points used to make 4-point curves were 3.6,4.4,5.2,6.0.