Nuclear Asphalt Gauge Testing
Acknowledgement

The financial support for this project was provided by the Breakthrough Innovations Program. This program provides an alternative source of funding that bypasses the usual budgetary channels, allowing and encouraging employees at all levels to stretch their creative wings.
The Minnesota Department of Transportation (Mn/DOT) has been performing asphalt extraction testing on bituminous road materials for more than 50 years. Currently, Mn/DOT annually performs about 3,500 extractions. Extraction testing requires the use of chlorinated solvents, which generates a considerable amount of hazardous liquid waste that must be disposed of by strictly following increasingly complex and stringent federal regulations.

The objective of this research project was to replace or supplement the current chemical extraction method for testing the asphalt content of road construction bituminous mixtures with nuclear asphalt gauge testing.

This research led to the following conclusions:
1. Nuclear asphalt gauge testing gives asphalt cement content results that are at least as accurate as solvent extraction testing.
2. Gradation testing cannot be done using nuclear asphalt gauge testing procedures.
3. Nuclear asphalt gauge testing works well for bituminous materials containing up to about 20 percent recycled asphalt pavement (RAP).
NUCLEAR ASPHALT GAUGE TESTING

Final Report

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The authors and the Minnesota Department of Transportation do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.
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INTRODUCTION

OBJECTIVE
To replace or supplement the current chemical extraction method for testing the asphalt content of road construction bituminous mixtures with nuclear asphalt gauge testing.

BACKGROUND
The Minnesota Department of Transportation (Mn/DOT) has been performing asphalt extraction testing on bituminous road materials for more than 50 years. Currently, Mn/DOT annually performs about 3,500 extractions. Asphalt analysis is vital to ensure quality pavements for Minnesota roads. Extraction testing requires the use of large amounts of chlorinated solvents. The chlorinated solvents used for the tests are hazardous to testing personnel and to the environment. The testing generates considerable amounts of hazardous liquid waste that must be disposed of by strictly following increasingly complex and stringent federal regulations. In addition, volatile chlorinated solvent vapors are discharged by laboratory safety hood exhaust fans (Photograph 1). Potential liability problems due to hazardous waste handling and/or disposal are an ongoing concern.
The Bituminous Office of Materials Research and Engineering researched replacing hazardous chlorinated solvents with biodegradable solvents made from citrus peels. The Bituminous Office laboratory did determine through this research that biodegradable solvents could successfully be substituted for the chlorinated solvents used in extraction testing. This research also determined that the use of chlorinated solvents could be phased out by Mn/DOT extraction laboratories. Biodegradable solvent extraction testing accuracy requires that a final alcohol rinse be done on the extracted aggregate. However, the Mn/DOT Industrial Hygienist determined that Mn/DOT laboratories would not be permitted to use alcohol for testing purposes. Solvent hoods used by

Photograph 1. Extraction Laboratory Safety Hood
Mn/DOT laboratories have not been fitted for fire safety.

Further studies by the Bituminous Office suggested that the new technology of nuclear asphalt gauge analysis could be used by Mn/DOT to test the asphalt content of bituminous materials. The Bituminous Office purchased two nuclear asphalt gauges for evaluation (Photograph 2). Preliminary testing results obtained with the nuclear asphalt gauges at the Ft. Snelling Laboratory and the Bituminous Office laboratory were promising.

Photograph 2. Troxler Nuclear Asphalt Gauge

A Breakthrough Innovations grant of $32,400 was awarded in October 1993 to the Bituminous Office to purchase four additional nuclear asphalt gauges.
REPORT

The $32,400 Breakthrough Innovations grant was used to purchase four Troxler Model 3242 nuclear asphalt gauges. The nuclear gauges were given to the Duluth, Bemidji, Mankato, and Detroit Lakes District Laboratories. Gauges for the remaining districts were purchased with district and Materials Research and Engineering funds. Every outstate district has a nuclear asphalt gauge and the Bituminous Office has two nuclear gauges for a total of nine gauges.

The Bituminous Office arranged for Troxler Laboratories to give radiation safety and nuclear gauge hands-on training for district and Bituminous Office laboratory personnel at Materials Research and Engineering.

PROJECT IMPLEMENTATION TASKS

The Bituminous Office identified eight tasks to be completed to evaluate the feasibility of replacing solvent extraction of bituminous road materials with nuclear asphalt gauge testing:

TASK 1: Distribution of nuclear asphalt gauges to districts.

TASK 2: Nuclear safety and nuclear gauge hands-on training for laboratory personnel.

TASK 3: Selection of research projects for participating districts.

TASK 4: Preparation of calibration samples by each district.

TASK 5: Sharing of calibration data between remote gauges.
TASK 6: Statistical comparisons of extraction and nuclear testing results, costs, and times.

TASK 7: Analysis of the effects of aggregate and recycled materials contents on calibration curves and test results.

TASK 8: Conclusion and possible implementation through a draft specification.

PROJECT SCHEDULE

A project schedule to research nuclear gauge testing was distributed to the Materials Research & Engineering and district laboratories (Table 1).

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<thead>
<tr>
<th>Task</th>
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Table 1. Project Schedule
FINANCIAL BASELINE

The Bituminous Office identified a 1993 financial baseline:

1. Statewide trichloroethane costs were $69,425 (Table 2).
2. Materials Research & Engineering Extraction Laboratory personnel costs were $61,700.

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<th>PURCHASE PICK-UP FEE</th>
<th>STATE FEE</th>
<th>DISPOSAL</th>
<th>LAB TOTAL</th>
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Table 2. TRICHLOROETHANE EXTRACTION 1993 COSTS. (AVERAGED TO TWO PICK-UPS PER YEAR)

The Bituminous Office contacted and interviewed laboratory personnel from the Alaska DOT and the Missouri DOT about their use of nuclear asphalt gauge testing. Both of these transportation departments are exclusively testing bituminous road materials with nuclear asphalt
gauges. Dale Payne of the Missouri DOT and Tom Fisher of the Alaska DOT report that they are satisfied with the fast turnaround time, accuracy, and ease of nuclear asphalt gauge testing.

The Missouri DOT has been using nuclear testing for the past four years and is presently using 60 nuclear asphalt gauges to analyze bituminous road materials (Exhibit 1). New calibration samples are prepared for every new mix design. Cross-calibrations to two centrally located master nuclear gauges are periodically performed on all of their nuclear gauges to ensure uniform gauge accuracy.

The Alaska DOT determined that nuclear asphalt testing gives an accuracy of better than 0.1 percent. The department's laboratories perform cross-calibration between gauges and perform new calibrations if recycled asphalt pavement content (RAP) of bituminous road mixes change more that 20 percent.

Caroline Herrera of the Texas DOT Bituminous Office was interviewed about their experience with nuclear asphalt gauge testing. The 25 Texas DOT districts have 100 nuclear asphalt gauges, and the department determined that nuclear asphalt gauge testing is equal or superior to solvent asphalt testing. Texas DOT policy permits road contractors to use either nuclear gauge or solvent testing for asphalt analysis.

Braun Intertec Inc., in collaboration with the Bituminous Office, has performed and evaluated nuclear asphalt testing using eight bituminous mix designs. Braun Intertec Inc. sent a written
report to the Bituminous Office concerning their findings (Exhibit 2).

The Braun Inc. researchers determined that nuclear asphalt gauge analysis produces results that equal or exceed other current methods of asphalt analysis. The Bituminous Office confirmed the Braun Intertec Inc. results by performing asphalt testing on the Braun Intertec Inc. samples using nuclear asphalt gauge testing.

The District 8 Extraction Laboratory did considerable evaluation of nuclear asphalt testing versus solvent extraction and concluded that nuclear testing is accurate. The laboratory also concluded that preparing calibration samples for changes in aggregate or RAP can be too time consuming.

Another district laboratory evaluated nuclear asphalt testing and concluded that their nuclear gauge gave variable results. Laboratory personnel complained that their nuclear gauge was defective. The nuclear gauge was evaluated at Material Research and Engineering and no defects in the gauge were discovered. The nuclear gauge was then returned to Troxler Electronics for testing. The gauge was in perfect working condition. This gauge was returned to the district laboratory where laboratory personnel again complained of variable testing results. These variable test readings appear to be due to operator technique.
CONCLUSIONS

Nuclear asphalt gauge testing gives AC content results that are at least as accurate as solvent extraction testing. However, gradation determinations also are required for bituminous pavement quality control/quality assurance (QC/QA). Gradation testing cannot be done using nuclear asphalt gauge testing procedures. The testing of asphalt content of asphalt mixtures using asphalt content gauge analysis can be used to supplement solvent extraction testing. Asphalt gauge testing cannot, at this time, be used to completely replace solvent extraction testing. Preparing calibration curves for each mix design is a problem that has not yet been completely resolved. Nuclear asphalt gauge testing works well for bituminous materials containing up to about 20 percent RAP. RAP contents above about 20 percent require that new calibrations samples be prepared, otherwise uncertain results may be obtained.

Nuclear asphalt testing is, however, an excellent nondestructive tool to monitor asphalt content uniformity and for the additional research required for removing chlorinated solvents from Mn/DOT’s QC/QA program. The Federal Highway Administration has endorsed the use of nuclear asphalt testing for QC/QA control of asphalt pavements.
IMPLEMENTATION

Nuclear asphalt gauge testing is part of a new asphalt testing procedure being developed by the Bituminous Office. This new procedure will reduce the number of extractions performed by Mn/DOT laboratories. The projected financial baseline of the new testing procedure is estimated to be:

1. Statewide solvent costs $14,000.
2. Materials Research & Engineering Extraction Laboratory personnel costs $14,000.
3. Statewide solvent and Materials Research and Engineering total savings of $103,125.

<table>
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<th>PRESENT</th>
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<th>SAVINGS</th>
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Table 3. PROJECTED FINANCIAL BASELINE.
EXHIBIT 1

MISSOURI DOT
TEST METHOD T54-10-94
MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
DIVISION OF MATERIALS AND RESEARCH
Jefferson City, Missouri

Test Method T54-10-94

ASPHALT CEMENT CONTENT OF BITUMINOUS MIXTURES
BY THE NUCLEAR METHOD

Issued October 1, 1994

1.0 SCOPE.

1.1 This test method describes the quantitative determination of the asphalt cement content of bituminous mixtures by testing a sample with a device that utilizes neutron thermalization techniques. This method can be used for rapid determination of the asphalt cement content of bituminous paving mixtures. Testing can be completed quickly so that adjustments, if necessary, can be made in the asphalt cement metering system with a limited amount of mix production. This procedure is useful in the determination of asphalt cement content only. This Test Method is to take the place of Test Method T54-7-92 dated July 1, 1992.

1.2 Unless the test sample is completely free of moisture, the percent moisture must be determined as described in Paragraph 8.6 of this test method and a correction made to compensate for the moisture.

2.0 APPARATUS.

2.1 Gauge, Model 3241-C manufactured by Troxler Electronic, Inc. with instruction manual.

2.2 Mixing Machine, Hobart A-200 with a 20 quart bowl or similar mixer with a wire whip mixing paddle (Central Laboratory).

2.3 Balance, capable of weighing to 15 kg, readable to 0.1 g (Central Laboratory).

2.4 Balance, capable of weighing to 12 kg, readable to 1 g (Field Laboratory).

2.5 Oven, capable of heating to 375 ± 5F (190 ± 3C).

2.6 Straightedge, steel, approximately 18 in. in length.

2.7 Plywood, 3/4 in. or thicker, or metal plate 3/8 in. or thicker having an area slightly larger than the sample pans.

2.8 Spoons, scoops, mixing bowls, trowel, and/or spatula.

2.9 High density polyethylene sheeting approximately 3/16" x 7" x 9". Size is not critical, however each size will produce specific readings. the readings should be within the intended working range of the gauge.

3.0 PRECAUTIONS.

3.1 Gauge operators shall have received approved safety training and shall wear a dosimetry badge provided by the department.

3.2 Since the gauge equipment measures the total amount of hydrogen in the sample, this procedure is sensitive to changes in moisture content. It must be remembered that both asphalt cement and water contain hydrogen.

3.3 Keep any other source of neutron radiation at least 30 feet from the equipment. Do not use the equipment where large amounts of hydrogenous material may be moved during the calibration or testing procedures (for example, people, water, trucks loaded with bituminous mix, or plastic materials.) A change in the hydrogen background during testing may affect final test results.

3.4 The operator should be aware of changing conditions that could affect gauge results.
Additional standardization testing should be performed, as described in Paragraph 4, if changes occur.

4.0 STANDARDIZATION.

4.1 Before operating a gauge in a new location, the surrounding conditions will be visually evaluated to determine if conditions are present which would affect the operation of the gauge. If visual evaluation is acceptable, proceed with the 200 count stability test.

4.2 200 Count Stability Test. The count time for the 200 count stability test is to be 4 minutes. A 200 count stability test is to be performed in accordance with Annex A1 or Annex A2, as applicable, every 30 days during use and if 30 days have passed since the gauge was last used. A passing 200 count stability test must be achieved before using the gauge. Record all 200 count stability test results, passing or failing, and note any changes made in the surrounding environment or test conditions.

4.3 Background Test. A background test is to be performed at least daily prior to testing samples. The test period is to be 16 minutes. The gauge is to be left in the "power on" condition throughout the day. Record all background counts.

5.0 LAB-TO-FIELD GAUGE CROSS CALIBRATION.

5.1 The transfer of a calibration from the laboratory gauge to the field gauge requires that a correlation between the gauges be established. This is accomplished by performing a cross calibration between the field gauge and the master gauge in the Central Laboratory. The Troxler's internal capability to correlate the gauges is to be used. This cross calibration is to be done annually, and the counting of samples in each gauge is to be within 24 hours of each other. Before beginning a cross calibration, the standardization procedures in Paragraph 4 are to be performed for each gauge. Record the results of the cross calibration.

5.2 Cross calibrations will be done with seven (7) samples. The seven samples will have asphalt cement contents of 3.0, 3.5, 4.2, 4.9, 5.6, 6.3, and 7.0 percent. The asphalt cement contents can vary ± 0.10 percent from the target content and are based on 100 percent mixture. The aggregates used will be from a mixture that was approved at not less than 6.0 percent asphalt content.

5.3 Cross calibration samples will be prepared in accordance with applicable parts of the paragraph on calibration sample preparation.

6.0 CALIBRATION SAMPLE PREPARATION.

6.1 A calibration will be performed by the Central Laboratory for each job-mix formula.

6.1.1 Materials for calibration samples are to be obtained in the same manner as trial mix materials for bituminous mixtures.

6.1.2 Samples for calibrating the gauge are to be prepared in a precise manner. The calibration is sensitive to the type of aggregate, percentage and source of asphalt cement, and aggregate gradation.

6.1.3 All aggregate will be separated into individual sieve fractions above the No. 8 sieve and recombined in the necessary quantities with the material passing the No. 8 sieve to meet the approved job-mix formula for which a calibration is being performed.

6.2 Three samples will be prepared for the calibration plus an initial batch to "butter" the mixture bowl and stirrers. This "butter" batch will be mixed at the low asphalt content point. The asphalt cement content of one sample will be the same as the job-mix formula, one will be 0.8 percent above and one 0.8 percent below the job-mix formula based on 100 percent mixture composition. These asphalt cement contents when calculated can vary ± 0.10 percentage point from the target content. The mixing order will be from lowest asphalt cement content to highest.

6.2.1 Each batch size will be as follows, unless additional material is needed to fill the sample pan.

Limestone mixtures - 8,000 grams
Porphyry or Steel Slag mixtures - 10,000 grams
6.3 The prepared aggregate and bituminous material will be heated to a mixing temperature of 325 ± 5 F (163 ± 3 C) for wet mixing by the mechanical mixer.

6.4 Determine and record the tare weight ($W_t$) of the mixing bowl to the nearest 0.1 gram. When both aggregate and bituminous material are at the required mixing temperature and the mixing bowl is approximately the temperature of the aggregate, the aggregate is to be added to the mixing bowl and a weight determined ($W_{at}$) to the nearest 0.1 gram and recorded. The amount of asphalt cement to obtain the desired asphalt content will be added to the aggregate in the mixing bowl. The weight of the combined components and the bowl ($W_{ct}$) will be determined to the nearest 0.1 gram and recorded.

6.4.1 The weight of the aggregate ($W_a$) and the combined components ($W_c$) is to be determined as follows:

$$W_a = W_{at} - W_t$$

$$W_c = W_{ct} - W_t$$

6.5 The calculated percent asphalt content (%AC) of the prepared sample will be determined as follows and the result rounded to the nearest 0.01 percent.

$$\% \text{AC} = \left( \frac{W_c - W_a}{W_c} \right) \times 100$$

6.6 After determining the weight of the asphalt cement added to the mixing bowl, mix the sample for 2 minutes with the mechanical mixer.

6.7 After mixing, place the mixture into a batching pan. The sides of the bowl and stirrers are to be cleaned of mixture residue by scraping with a small limber spatula. The bowl and stirrers are not to be wiped with cloth or washed clean with solvent, except at the end of a calibration.

7.0 GAUGE CALIBRATION.

7.1 A calibration will be performed by the Central Laboratory for each bituminous mixture. Before the calibration is performed, the standardization procedures as described in Paragraph 4 are to be performed. A calibration will be performed entirely in one gauge. That gauge serial number is to be recorded with the calibration results. All samples are to be mixed as specified in Paragraph 6 and counted 16 minutes.

7.2 To begin a calibration, a test sample weight must be determined. The sample for the calibration with the lowest asphalt cement content is to be used to determine the test sample weight. Determine sample pan weight and record. Fill a clean sample pan one half full, then evenly distribute the sample in the pan with a trowel or spatula. Care should be taken not to exert pressure on the sample. Fill the remainder of the pan until the bituminous mixture in the pan is rounded slightly above the top of the pan. Level the top of the bituminous mixture using a spatula or trowel to an even head above the top lip of the pan. This head (approximately 1/2-in.) should be sufficient to create a condition that requires moderate effort to compress the sample into the sample pan. Use the metal or plywood plate to consolidate the bituminous mixture until it is even with the top of the pan. This should be done by placing the pan on the floor, placing the plate on top of the sample pan, and standing on the plate. Weigh and record the test sample weight (sample pan not included). This weight will be used for all calibration samples and all field or laboratory test samples using this calibration.

7.2.1 Prepare the remaining two samples at the test sample weight, ± 2 grams, as described above.

7.2.2 Each sample is then to be counted for 16 minutes in the master gauge.

7.2.3 The calibration curve is prepared by using the sample counts. The gauge will be used to develop this calibration curve. The percent asphalt cement content used will be based on 100 percent mixture. The curve will be a linear regression analysis of the gauge counts versus percent asphalt cement content. To be considered acceptable, a calibration should have a coefficient of correlation (Fit Coefficient) equal to or greater than 0.995.

7.2.4 The curve variables (A1 and A2), laboratory gauge background count, calibration sample weight, and the laboratory calibration gauge serial number will be transmitted to the field for use in the field gauges.
7.3 The calibration of a gauge with mixtures incorporating recycled asphalt pavement (RAP) presents special problems. The RAP must be of uniform gradation, asphalt cement content, and asphalt cement type. The RAP is to be mixed into the calibration samples in the same proportion as it will be used in the bituminous mixture. The calculated percent asphalt cement content used in the calibration will be the summation of added asphalt cement and asphalt cement content of RAP determined in accordance with AASHTO T 164, Method A.

8.0 FIELD TESTING.

8.1 The location of operation of a gauge is to be evaluated for acceptability using the standardization procedures described in Paragraph 4.

8.2 The laboratory calibration values $A_1$, $A_2$, background count, and bituminous mixture test sample weight must be entered into the field gauge. When the gauge asks for a value of $A_3$, enter $+0$. The values of $A_1$ and $A_2$ for the transferred calibration may differ from the laboratory calibration values for $A_1$ and $A_2$.

8.3 Obtain samples of the freshly produced bituminous mixture in accordance with AASHTO T 168 or by sampling from a flowing stream discharge.

8.3.1 A sample from a flowing stream discharge is to be obtained at random in at least three approximately equal increments so that when combined there is a sample at least four times the sample size required for testing. Take each increment from the entire cross section of the material (stream) as it is being discharged. It may be necessary to have a special sampling device constructed for use at each particular plant. The sampling device should consist of a container of sufficient size to intercept the entire cross section of the discharge stream and hold that quantity of material without overflowing. A set of rails may be necessary to support the container as it is passed through the discharge stream. Samples obtained from stream discharge will be quartered as specified in AASHTO T 248, Section 9.1.1.

8.4 Preparation of field test mixture samples will be as follows:

8.4.1 Fill a clean, tared, sample pan one half full, then evenly distribute the sample in the pan with a trowel or spatula. Care should be taken not to exert pressure on the sample. Fill the remainder of the pan until the test sample weight is achieved. Level the top of the bituminous mixture using a spatula or trowel to an even head above the top lip of the pan, approximately 1/2 inch. Use the metal or plywood plate to consolidate the bituminous mixture until it is even with the top of the pan. This should be done by placing the pan on the floor, placing the plate on top of the sample pan, and standing on the plate. The sample should be reweighed to determine if the test sample weight, not including sample pan weight, has been achieved. Variation from this weight of ± 20 grams is acceptable.

8.5 Samples are to be tested in the gauge for a time period of 16 minutes. Record the gauge counts and percent asphalt content. Precautions as described in Paragraph 3 are to be carefully followed.

8.6 The test sample must be checked for moisture content. If moisture is present, the percentage determined must be subtracted from the apparent asphalt cement percentage as indicated by the nuclear gauge counts.

8.6.1 The determination of moisture content may be made in accordance with AASHTO T 110, or MHTD T53-89. These determinations may be done with a companion sample or with the test sample after testing in the nuclear gauge.
ANNEX A1

A1 Procedure for 200 Count Stability Test using Troxler Software Version 2.13. The software version may be verified during the initial RAM test.

A1.1 Move the gauge to an undisturbed location at least 30 feet from other neutron sources (For example: other asphalt content gauges). This test takes approximately 13 1/2 hours to complete.

A1.2 Turn the gauge on and allow it to run the RAM Test.

A1.3 At the prompt "SAMPLE DATA -- ERASE", press "NO". Note: This prompt may or may not come on the screen. If the prompt does not come up, proceed with the next step.

A1.4 If the count time is something other than 4 minutes, change the count time to 4 minutes.

A1.5 Take a 4 minute background count, record and use.

A1.6 Place the polyethylene sheet in the chamber and close the chamber door.

A1.7 Activate the factory calibration.

A1.8 Press the following keys in the designated sequence: "SHIFT", "SPECIAL", "." and "0".

A1.9 At the prompt "ALL SAMPLE DATA WILL BE LOST! DO YOU WANT TO CONTINUE?", press "YES".

A1.10 At the prompt "SELECT: 1=STORE DATA, 2=DUMP DATA, 3=ERASE & EXIT", press "1" to store data while the 200 count stability test is being run.

A1.11 At the prompt "INPUT NUMBER OF PASSES (1-200)", input "200" and press "ENTER".

A1.12 "PASS # 1 OF 200", should come up at the top of the screen with "TIME XXX SEC" at the bottom of the screen. This indicates the 200 count stability test has begun.

A1.13 At the end of the test period, the screen display will show the mean and standard deviation for Percent Asphalt Cement, Raw Count 1, and Raw Count 2. Also Pass/Fail information will be displayed for either the Percent Asphalt Cement or Raw Count 1 and Raw Count 2. If the gauge passes the 200 count test, record the displayed information and proceed with step A1.14. If the gauge fails on one or both of the Raw Counts, record the displayed information and rerun the 200 count test. If the gauge fails on the Raw Count a second time, again record the information and contact the Central Laboratory. If the gauge fails on percent asphalt, record the displayed information and calculate the precision ratio for each Raw Count as follows:

$$PR = \frac{RSD}{RM^{0.5}}$$

Where: PR = Precision Ratio

RSD = Raw Count Standard Deviation

RM = Raw Count Mean

If $0.902 < PR < 1.098$ for both Raw Counts, the gauge is considered passing, otherwise calculate the precision limit in accordance with Annex A3.

A1.14 Press "ENTER"

A1.15 At the prompt "SELECT: 1=STORE DATA, 2=DUMP DATA, 3=ERASE & EXIT", select "3" (ERASE & EXIT)

A1.16 At the prompt "ARE YOU SURE, YOU WANT TO ERASE DATA", press "YES"

A1.17 Gauge should come back to "GAUGE READY" display.
ANNEX A2

A2 Procedure for 200 Count Stability Test using Troxler Software Version 2.18. The software version may be verified during the initial RAM test.

A2.1 Move the gauge to an undisturbed location at least 30 feet from other neutron sources (For example: other asphalt content gauges). This test takes approximately 13 1/2 hours to complete.

A2.2 Turn the gauge on and allow it to run the RAM Test.

A2.3 At the prompt "SAMPLE DATA --- ERASE", press "NO". Note: This prompt may or may not come on the screen. If the prompt does not come up, proceed with the next step.

A2.4 If the count time is something other than 4 minutes, change the count time to 4 minutes.

A2.5 Take a 4 minute background count, record and use.

A2.6 Place the polyethylene sheet in the chamber and close the chamber door.

A2.7 Activate the factory calibration.

A2.8 Press the following keys in the designated sequence: "SHIFT", "SPECIAL", "1", "9", "YES", and "4".

A2.9 At the prompt "ALL SAMPLE DATA WILL BE LOST! DO YOU WANT TO CONTINUE?", press "YES".

A2.10 At the prompt "SELECT: 1=STORE DATA, 2=DUMP DATA, 3=ERASE & EXIT", press "1" to store data while the 200 count stability test is being run.

A2.11 At the prompt "INPUT NUMBER OF PASSES (1-200)", input "200" and press "ENTER".

A2.12 "PASS # 1 OF 200", should come up at the top of the screen with "TIME XXX SEC" at the bottom of the screen. This indicates the 200 count stability test has begun.

A2.13 At the end of the test period, the screen display will show the mean and standard deviation for Percent Asphalt Cement. Press "yes" and the screen display will show the mean and standard deviation for Raw Count 1, and Raw Count 2. Also Pass/Fail information will be displayed for either the Percent Asphalt Cement or Raw Count 1 and Raw Count 2. If the gauge passes the 200 count test, record the displayed information and proceed with step A2.14. If the gauge fails on one or both of the Raw Counts, record the displayed information and rerun the 200 count test. If the gauge fails on the Raw Count a second time, again record the information and contact the Central Laboratory. If the gauge fails on percent asphalt, record the displayed information and calculate the precision ratio for each Raw Count as follows:

\[
PR = \frac{RSD}{(RM)^{0.5}}
\]

Where: \( PR \) = Precision Ratio

\( RSD \) = Raw Count Standard Deviation

\( RM \) = Raw Count Mean

If \( 0.902 \leq PR \leq 1.098 \) for both Raw Counts, the gauge is considered passing, otherwise calculate the precision limit in accordance with Annex A3.

A2.14 Press "ENTER"

A2.15 At the prompt "SELECT: 1=STORE DATA, 2=DUMP DATA, 3=ERASE & EXIT", select "3" (ERASE & EXIT)

A2.16 At the prompt "ARE YOU SURE, YOU WANT TO ERASE DATA", press "YES"

A2.17 Gauge should come back to "GAUGE READY" display.
ANNEX A3

A3 Procedure For Calculating Precision Limit

A3.1 If the ambient temperature during the 200 count stability test changes more than 5°F the gauge compares the percent asphalt data rather than the raw count data. Due to differences between actual background count and the factory background the comparison may be erroneously displayed as failing. This describes the procedure used to calculate a new precision limit.

A3.2 Given: Factory Calibration Background = 2200

A3.3 Given: Factory A(2) = 0.0030276

A3.4 Calculate mean gauge count:

\[ MGC = \frac{(AC + 2.971852)}{FA2} \]

Where:

- MGC = Mean Gauge Count
- AC = Percent Asphalt displayed at end of 200 count test.
- FA2 = Factory A(2)

A3.5 Calculate gauge A(2):

\[ GA2 = \frac{(FA2)(GBKG)}{(FBKG)} \]

Where:

- GA2 = Gauge A(2)
- FA2 = Factory A(2)
- GBKG = Gauge Background Count
- FBKG = Factory Calibration Background Count

A3.6 Calculate actual gauge count:

\[ AGC = MGC + (GBKG - FBKG) \]

Where:

- AGC = Actual Gauge Count
- MGC = Mean Gauge Count

A3.7 Calculate the new precision limit:

\[ PL = \frac{(GA2)(AGC)^{0.5}}{(PS)^{0.5}} \]

Where:

- PL = Precision Limit
- GA2 = Gauge A(2)
- AGC = Actual Gauge Count
- PS = Prescale (PS = 4 for 1 min. count, PS = 16 for 4 min. count, PS = 32 for 8 min. count, and PS = 64 for 16 min. count.)

A3.8 Compare the calculated precision limit to the percent asphalt standard deviation displayed by the gauge. If the calculated precision limit is greater than the displayed standard deviation for percent asphalt, the gauge has passed the 200 count stability test. If the calculated precision limit is less than the standard deviation for percent asphalt, the gauge has failed the 200 count stability test and should be run a second time. If the gauge fails the 200 count stability test twice, contact the Central Laboratory.
EXHIBIT 2

BRAUN INTERTEC CORPORATION

AN EVALUATION OF
NUCLEAR ASPHALT CONTENT GAUGE
AN EVALUATION OF NUCLEAR ASPHALT CONTENT GAUGE

Completed research regarding the nuclear asphalt content gauge

Project BABX-93-355
February 18, 1994

Braun Intertec Corporation
February 17, 1994

Mr. Curtis M. Turgeon, P.E.
Materials Research and Engineering Laboratory
1400 Gervais Avenue
Maplewood, MN 55109

Dear Mr. Turgeon:

Re: Evaluation of Nuclear Asphalt Content Gauge

As you authorized on June 9, 1993, we have completed our research regarding the nuclear asphalt content gauge. Data from this research will be used to help develop specification changes using the nuclear asphalt content gauge in lieu of the current chlorinated solvent extractions.

Background

Braun Intertec received a nuclear asphalt content gauge from Mn/DOT in early August of 1993. This gauge is a Troxler Model 3241-C, Universal Sample System. This gauge determines asphalt content by counting the number of slowed neutrons emitted from Americium-241: Beryllium source through a hydrogen bearing material. As requested, the plug fixture method of asphalt content determination was utilized with this gauge.

Data

Calibrations
A total of eight calibrations were generated on mix designs in the Braun Intertec Minneapolis lab from August through October of 1993. Sixteen minute standard or background counts were taken prior to each of these calibrations. The individual tests consisted of four readings of four minutes each while rotating and turning over the plugs per the manufacturer’s recommendations. Each calibration was developed using data from four or five different asphalt contents.

Each of the gauge-derived calibrations are included in the attached Data Section. For each of the calibrations we have included the counts, equation constants, the fit coefficient, and the difference between the actual asphalt content and the gauge-calculated asphalt content at each of the data points.

The time spent for developing the four-point calibration was approximately one and a half hours of machine time, with about 20 minutes of actual hands-on technician time. The time
spent for a five-point calibration, including the time to batch, mix and prepare the Marshall specimens for the extra point, was approximately two hours of machine time with approximately an hour and a half of hands-on technician time.

One set of gauge calibration transfer samples were batched, tested and delivered to the state on October 12, 1993. These are the samples that would be used to correlate our gauge to one of your gauges. We would like to note that, per the manufacturer's instructions, these samples should be tested by both gauges on the same day. This calibration data is also attached to this report.

Test Results
Marshall samples compacted on field projects were retrieved from these projects and returned to our Minneapolis office. Using the calibrations developed earlier, the asphalt content was measured in these Marshall specimens in late November and December of 1993. A 16-minute background count was taken twice per day and the asphalt content was again measured for four minutes for each of the four readings per pair of Marshalls. The actual hands-on technician time was approximately five minutes per test.

A total of 207 asphalt content determinations were made from six projects of varying courses, resulting in ten different sets of data. These test results are tabulated in the attached Data Section. Also shown on the tabulations are the percent asphalt contents by the spot check method and by the Rice calculation method.

A total of eight extraction tests were run in the field on these samples. To provide additional correlation of the asphalt content gauge to the extraction test result, a total of 30 additional extractions were run on the Marshall specimens after nuclear testing in our Minneapolis laboratory. These extractions were run following the Colorado vacuum method, and a 0.3 percent retention factor has been added to the extracted asphalt content. These results are also tabulated with the other asphalt content determinations in the attached Data Section.

Data Analysis
Overall averages of the asphalt content determinations by the various methods have been calculated and are shown on the attached tabulations. Moving averages of four results are also shown. We have also calculated the standard deviation of the nuclear test results when compared to the average of the asphalt content determinations using all the other methods. On recycled mixes, the asphalt content by the spot check method has been calculated by the formula:

\[ \% \text{RAP} \times \% \text{RAP AC} + \text{spot check} \]

Standard deviations of the test results were plotted against the fit coefficient of the calibration data and a linear regression analysis was made. The data is somewhat limited, but there
appears to be a relationship. Standard deviations of the nuclear asphalt results comparable to the ASTM D 2172 (extraction test) precision statement were obtained at approximately 0.993 fit coefficient. For the calibrations, the manufacturer recommends a minimum fit coefficient of 0.990, while ASTM and AASHTO recommend a minimum of 0.995. The ASTM precision statement uses the same sample, while our deviations are calculated on multiple samples. Thus, the 0.993 fit coefficient should be on the conservative side to obtain precision comparable to ASTM D 2172. This fit coefficient is called a correlation factor in ASTM and AASHTO specifications.

The apparatus precision, or gauge variability, at 6 percent asphalt was determined for calibration number 93609. Using this calibration data and 20, four-minute counts at 6 percent asphalt, the gauge variability was determined to be 0.0442 percent asphalt. AASHTO specifications require a maximum allowable of 0.05 percent. Results of this test are also attached.

Discussion
As stated earlier, AASHTO T287-93 and ASTM D 4125-92 require 0.995 or better fit coefficient for the calibration data. The manufacturer recommends 0.990 or better. Our data also indicates that a fit coefficient in the range of 0.995 to 0.990 would be appropriate. This will have to be determined.

ASTM, AASHTO and the manufacturer recommend a minimum of 3 points for the calibration. The three points would be at 1 percent below, 1 at and 1 percent above the design asphalt content. The current Mn/DOT procedure is to run four points at 1/2 percent asphalt increments. This will not necessarily provide asphalt contents 1 percent above and 1 percent below the design asphalt. Thus, a deviation from the nuclear test procedure or a change in the mix design requirements will be necessary.

ASTM, AASHTO and the manufacturer recommend aggregate counts checked each day to see if an aggregate gradation change has affected the calibration. ASTM says a new calibration may be needed if the difference is more than 0.5 percent, and AASHTO requires a new calibration if the difference is more than 0.3 percent. Neither ASTM nor AASHTO recognize the slope offset or relative offset procedures described by the manufacturer.

Both ASTM and AASHTO say to follow the manufacturer's instructions regarding the actual operation of the equipment. They require background counts, equal to or greater than the test count, be taken daily. The manufacturer recommends 16-minute standard counts and four, four-minute test counts. These count times would comply with the ASTM and AASHTO requirements. ASTM also recommends a statistical stability test be run on new or repaired gauges once per month, and when the gauge readings appear suspect.
Currently, the plug fixture is not recognized by ASTM or AASHTO. According to a discussion with Mr. Dave Savage with AMRL on February 14, 1994, ASTM is currently in the balloting process to allow this fixture. Mr. Savage is not aware of any immediate changes taking place in AASHTO regarding the fixture. AASHTO also limits the asphalt content range to between 2 and 14 percent, which should not be a concern, and recommend new calibrations on a yearly basis and following repairs.

The manufacturer has developed a process of cross calibration which can allow calibrations on one gauge to be transferred to another. This cross calibration is not recognized by ASTM or AASHTO. According to the manual, this cross calibration can be done between the Model 3241C using the Americium-241: Beryllium, which we possess, and the Model 3241M using Californium-252, which the state has recently purchased a number of. Per the manufacturer's instructions, the cross calibration testing should be done by both gauges on the same day.

The use of these gauges will require additional training and record keeping. The following will be required, at a minimum:

1. Radiation safety training
2. Gauge operation
3. Licensing with applicable agencies
4. Transporting requirements
5. Storage requirements
6. Exposure monitoring (film badges)

The manufacturer stated that the radiation exposure under normal usage would be about 200 millirem per year. This is well below the 5,000 millirem per year allowed by the NRC.

During testing, we found the gauge tended to move a little each time the plug fixture was slid in place. At the end of the day, the gauge had moved back a considerable distance toward a wall. The standard count was found to have changed some, and a number of Marshalls were retested after securing the gauge and restandardizing. Up to a 1 percent difference in percent asphalt was noted in these retests. Thus, securing the gauge to maintain consistent background levels of radiation and hydrogen would appear critical.

Recommendations

It appears results can be obtained with a nuclear asphalt content gauge that are equal to or superior to the other current methods. However, the following will need to be addressed prior to implementation:

1. Pan method or plug fixture
2. Range of percent asphalt content in mix design/calibrations
3. Minimum fit coefficient of calibrations
4. Acceptance testing and/or plant control
5. Securing samples for daily aggregate count for acceptance testing
6. Mn/DOT or contractor developed calibration
7. Use of the cross calibration
8. Additional training
9. Gradation analysis of RAP mixes

General

We will be delivering our tested Marshall specimens to you shortly. It is our understanding that you will be testing all or some of these specimens to assess the cross calibration function of the gauge and possibly run additional extractions.

It has been our pleasure to assist you in this research. Should you have any questions regarding this data, please call David Clauson at (612) 942-4836 or Al Palmer at (612) 942-4893.

Sincerely,

David A. Clauson
Senior Engineering Assistant

W. Allen Palmer, P.E.
Senior Materials Engineer

Attachments:
Data Section