DOCUMENT # 1761

SPECIFICATION # _____

Save for Nue Study

PRECISION AND ACCURACY OF NUCLEAR ASPHALT CONTENT GAUGES IN DETERMINING ASPHALT CONTENT IN ASPHALTIC CONCRETE PAVEMENT

June, 1988

Anthony J. George, PE
Roadway Materials Engineer

Glenn Boyle
Bituminous Crew Leader

Donald E. Wence
Assistant Bituminous Crew Leader

Jeffrey L. Smith
Bituminous Mix Design Specialist

Russell Larmay
Student Trainee

Department of Transportation

HIGHWAY DIVISION

MATERIALS SECTION

DOCUMENT NUMBER 1761

Specification No.	**Report No.**
403	----
Report Date	**Type**
June 17, 1988	Research Report

Title

Precision and Accuracy of Nuclear Asphalt Content Gauges in Determining Asphalt Content in Aphaltic Concrete Pavement

Author

Anthony J. George, P.E. - Roadway Materials Engineer
Glenn Boyle - Bituminous Crew Leader
Donald E. Wence - Assistant Bituminous Crew Leader
Jeffrey L. Smith - Bituminous Mix Design Specialist
Russell Larmay - Student Trainee

Performing Organization (Name and Address)

Materials & Research Section
Oregon State Highway Divison
800 Airport Road
Salem, OR 97301

Sponsoring Agency (Name and Address)

Abstract

Key Words

Nuclear Asphalt Content Gauge
Asphaltic Concrete
Vacuum Extraction

Location

Library

TECHNICAL REPORT DOCUMENTATION PAGE

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents of this report do not necessarily reflect the views or policies of the Oregon Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENT

Special thanks to all agencies who participated in our nuclear asphalt content gauge survey and especially the agencies from whom we received test procedures and reports. Your help was instrumental in the preparation of this document.

TABLE OF CONTENTS

INTRODUCTION

Use of nuclear asphalt content gauges for determining asphalt content of asphaltic concrete pavement are gaining acceptance as an alternative method to the vacuum extraction process. The reasons nuclear asphalt content gauges are considered promising are as follows:

1) Recent technological advances in nuclear asphalt content gauges improved their precision and accuracy.

2) Relative safety of their use compared to the use of potentially hazardous solvents is advantageous.

3) A potential for lower overall test costs exist.

4) Ability to obtain more timely test results.

This study incorporated a multi-task work plan which included:

1) A literature review.

2) A survey of use by western states.

3) An in-house two phase testing program.
   A. Field bituminous mixture evaluation.
   B. Laboratory fabricated samples evaluation.

The first phase was performed by evaluating bituminous mixture used on the 12th Street SE - 24th Street SE Section, Mission Street (Salem) project. This involved performing four asphalt content determinations on each sample. Two tests were evaluated by the nuclear asphalt content gauges, Troxler 3241-B and Campbell AC-2. The remaining two tests were evaluated by the vacuum extraction procedure, one by OSHD laboratory personnel and one by OSHD field personnel.

The second phase compared a nuclear asphalt content gauge, Campbell AC-2, to known asphalt contents of samples prepared and analyzed by the Materials and Research Laboratory of the Oregon State Highway Division.

OBJECTIVES

The objectives of this study were to:

1) Confirm the precision and accuracy of the nuclear asphalt content gauge.

2) Compare the nuclear asphalt content gauge to the vacuum extraction results and to known asphalt contents.

3) Determine what effect sample moisture content and sample temperature has on nuclear asphalt content gauge results and establish an appropriate method of correction.

4) Evaluate the problems associated with aggregate acceptance based on cold feed gradations instead of extracted gradations, as is the current practice.

5) Evaluate other factors which could affect a decision to implement nuclear gauges in the field: (eg. calibration procedures, operator safety relative to vacuum extraction, relative costs, and relative speed of testing.)

6) Make recommendations on the feasibility of determining field asphalt content using nuclear asphalt content gauges.

LITERATURE REVIEW

A literature review was conducted to initiate this study. Information on the nuclear asphalt content gauge appeared limited, and obtaining appropriate documents was difficult. Efforts were further complicated, because much of the available research was conducted on or referred to outdated equipment. Nuclear gauges recently were significantly improved by advanced technology. Even so, the information obtained from these sources was helpful in understanding the history and progress of nuclear asphalt content gauges.

As the study progressed, more information arrived as a result of literature inquiries to other state, federal, and private agencies. It became apparent that many of these agencies believe the nuclear asphalt content gauges have great potential. However, all agencies did not decide to use nuclear asphalt content gauges. Many agencies are currently in the process of evaluating the instruments, and writing technical reports and test procedures from their findings.

The following findings and guidelines were established by the literature review:

1) A separate calibration curve is required for each individual mix design, asphalt brand, or asphalt grade.

2) Minor changes in gradation inherent to a specific mix design will have minor affects on the measured asphalt.

3) Calibration of the gauge by samples within a specific temperature range is required.

4) Preparation of samples required maintaining a constant weight, volume, and density of the mixture.

The literature review also documented concerns about the feasibility of using nuclear asphalt content gauges. The majority of concern were as follows:

1) Calibration.

2) Effects of moisture.

3) Effects of temperature.

4) How to obtain the aggregate gradation.

5) Relative safety.

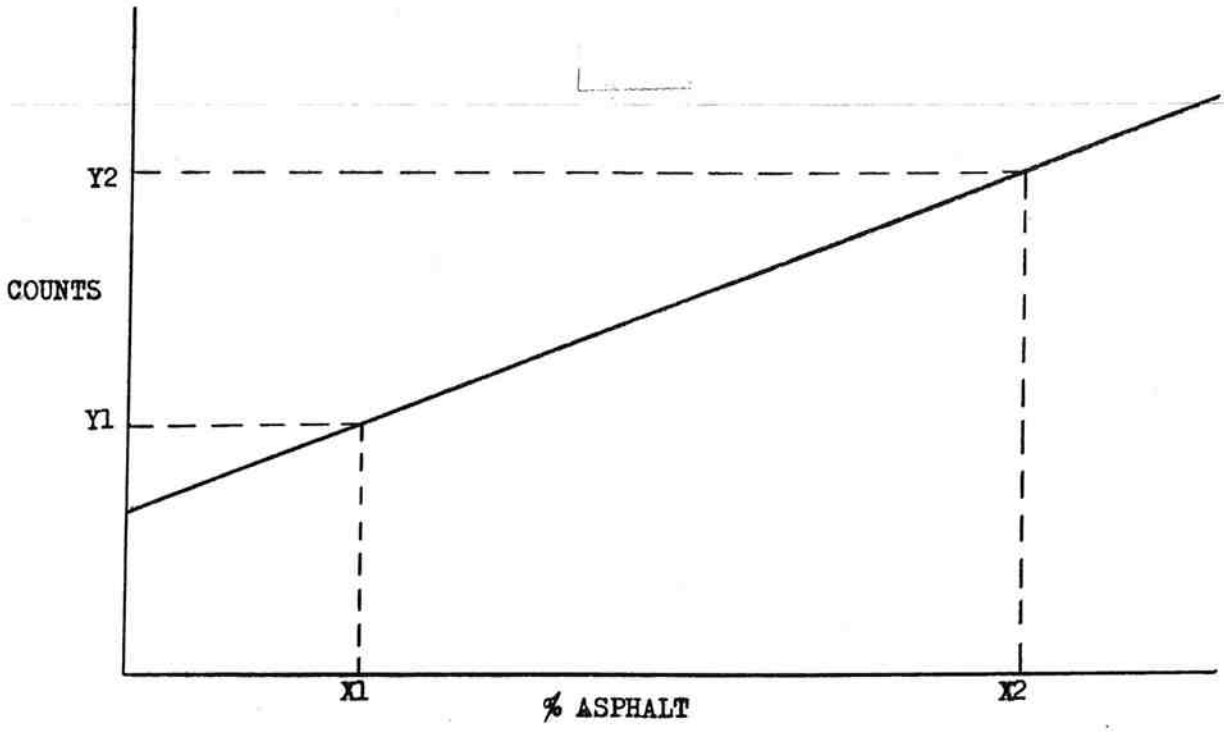
6) Relative cost and test efficiency.

Calibration

The calibration of the nuclear asphalt content gauge is the **most important step** in operating the gauge effectively. (1) All test results depend on the accuracy of the calibration curve. The operator should have a thorough knowledge of the nuclear asphalt content gauge before calibration is attempted.

It was found in the literature survey that calibration procedures are relatively simple and easy to perform. The key requirement is that calibration samples be fabricated from materials proposed for use on the project. A graphic representation of the calibration theory is illustrated in Figure 1. The operator prepares a minimum of two samples at known asphalt contents, which are plus and minus one percent of the design asphalt content. (2) These samples are tested in the gauge for a sixteen minute count. The gauge performs a regression routine on the calibration points to develop the best fitting line through the data. The slope and intercept are stored in the gauge and when a sample is tested, the gauge interprets the readings using the slope and intercept from the calibration curve to determine the asphalt content of the sample.

FIGURE 1



Effects of Moisture

The asphalt content determined by the gauge includes any moisture present in the sample. (3) The nuclear asphalt content gauge theory of operation is based on the principle of neutron moderation. Emitted neutrons are moderated by any hydrogen present within the sample. The hydrogen ions present in water and asphalt both moderate the emitted neutrons. It appears from the literature survey that a correction for moisture content is necessary to adjust the final value for asphalt content, although there was no clear consensus on the degree of adjustment to be used.

Effects of Temperature

Different sample temperatures can cause the sample to change in volume and density. (3) If the calibration procedure is accomplished at a temperature different than the test sample, the value for asphalt content could be consistently higher or lower than the true value. It appears the more dissimilar the temperatures the greater will be the discrepancy in the asphalt content results. Fortunately, it was found that technological advances resolved this phenomenon. Modern gauges are equipped with an automatic sample temperature compensation feature.

How to Obtain the Aggregate Gradation

When using a nuclear asphalt content gauge, aggregate gradation is not a direct result of the asphalt content determination process. Consequently, an alternative gradation testing procedure must be used. Some examples are:

1) Obtaining representative samples from an aggregate feed belt.

2) Use batch plants to assure proper aggregate gradation. (4)

3) Using biodegradable degreasers in the vacuum extractor.

Relative Safety

Radiation safety is stressed by the manufactures of nuclear asphalt content gauges. Their claim is that when this instrument is used in accordance with the manufacture´s operating instructions no danger exist to the operator. The literature and actual experience substantiates these claims.

Oregon State Highway Division obtained its first nuclear licence on September 16, 1966. Since that time no overexposure to

radiation has been documented to any OSHD personnel. Before any OSHD employee is permitted to operate a nuclear device, that person must successfully complete a radiation safety training course. While operating nuclear devices one must wear a film badge, which provides an individual record of exposure. OSHD has maintained records from film badge results for all personnel since 1972.

In 1987, OSHD outfitted twenty field laboratory trailers to accommodate chemical solvents used in the vacuum extraction process. These trailers are a conscientious safety effort by OSHD to provide their employees with a safe working environment. One in which the working atmosphere is within time-weighted average standards. (5) Although progress in the area of preventing overexposure to solvents has been achieved, records indicate there have been industrial accident claims associated with chemical solvents. Also complaints about headaches, nausea, and allergic reactions are common.

The chemical solvent preferred by OSHD is 1,1,1-trichloroethane, because of its relative low toxicity when compared to toluene, trichloroethylene, and methylene chloride. The solvent 1,1,1-trichloroethane is the only one in the above group that is not a suspect carcinogen. The Environmental Protection Agency is considering development of national emissions standards for hazardous air pollutants (NESHAP) for organic solvent cleaners under section 112 of the Clean Air Act. (6) Also under Part B of the Clean Air Act, the health effects resulting from stratospheric ozone depletion (potentially caused by CFC-113 and 1,1,1-trichloroethane) are currently being studied.

Disposal of hazardous waste is becoming a more controversial issue, consequently it is becoming more difficult and costly to dispose of these chemicals. On January 26, 1988 the Oregon State Public Interest Group presented a report, backed by 23,000 petition signatures, to Oregon's Governor, Neil Goldschmidt. This report asked him to take a preventive approach to toxic chemical pollution, and it recommended creating an institute to work on reducing the use of toxic chemicals. (7) To fund this effort a fee would be assessed to the purchaser of toxic chemicals, and the institute would provide technical assistance to reduce the reliance upon these chemicals. The nuclear asphalt content gauge would appear to be a reasonable alternative to chemical solvents based on relative safety.

Relative Cost and Test Efficiency

The vacuum extraction process is the established method of asphalt content determination in Oregon. The cost of a vacuum extractor is $870.00. It takes approximately one gallon of solvent to run one test. Each gallon costs $9.97. This includes

$4.93 to buy one gallon and $5.04 to dispose of one gallon. Not counting the time required for sample preparation, it takes two hours to run one asphalt content test. The cost per test for labor (based on OSHD Engineering Technician II salary at $1524 per month) is $17.52. Adding the cost for solvent to the labor cost, $27.55 per test is needed for vacuum extraction.

The cost of a nuclear gauge is approximately $5,500.00. Not counting the time required for sample preparation, it takes approximately five minutes to program the gauge and to run one test. Based on the same Engineering Technician II salary as above, it costs $0.73 (seventy-three cents) per test with the nuclear gauge.

Using the above cost analysis, the following is a comparison of the cost of vacuum extraction vs. nuclear gauge on two OSHD jobs:

1. POWELL BUTTE JUNCTION - ARNOLD ICE CAVES : This job has a combination of "B", "C" and "F" mix totalling 64,200 tons. Based on one test per 500 tons, 129 tests are required.

   Extraction = $3,553.95 (labor & solvent)

   Nuclear Gauge = $ 94.49 (labor, no solvent)

2. ABIQUA CREEK - "C" STREET (SILVERTON): This job has 7,200 tons of "C" mix. Based on one test per 500 tons, 15 tests are required.

   Extraction = $ 413.25 (labor & solvent)

   Nuclear Gauge = $ 10.99 (labor, no solvent)

The vacuum extractor requires accessories such as diatomaceous earth and filter papers, while the nuclear gauge requires calibration. These items were not included in the cost analysis.

The nuclear gauges have a one year manufacturer's warranty, and any repair cost within the first five years would be minimal, an estimated $350 per unit. An extended warranty program may be negotiated with the manufacturer. Also, a service contract may be purchased from the manufacturer, which includes an annual preventive maintenance check of the gauge by the manufacturer's laboratory during the off season.

It appears that the nuclear asphalt content gauge is cheaper to operate and could pay for itself in cost savings over several smaller projects or a few larger projects.

WASHTO NUCLEAR ASPHALT CONTENT GAUGE SURVEY

In November, 1987, a survey of the WASHTO states was conducted on the use of the nuclear asphalt content gauge. The questioning format concentrated on areas of concern about the nuclear asphalt content gauge, and an attempt was made to solicit candid responses about the respective nuclear asphalt content gauge programs. The results of the survey are presented in Figure 2.

Fifteen state agencies and the Federal Highway Administration participated in the survey. Thirteen are presently using the nuclear asphalt content gauges in some part of their testing program, and four are using the gauges exclusively for acceptance testing. Three agencies permit the choice between the nuclear asphalt content gauge or traditional methods (vacuum extraction and hot reflux) for acceptance testing. The predominate gauge in use is the Troxler, Model 3241-B.

Among the states, there was no clear standard for asphalt content (eg. vacuum extraction, tank stick, or hot reflux). Therefore, it is difficult to compare nuclear gauge results against any one standard.

The most variable response was to the question about what method to use for moisture determination. The survey indicated an acceptance of varying methods among agencies and multiple methods within states. This seems to be based upon local conditions, available equipment, and agency policies. Moisture was corrected at a 1:1 ratio against the asphalt content value.

The question on how to perform the gradation analysis gave most agencies the greatest difficulty. Although grading obtained from cold feed samples was most common, there was not a great deal of confidence in this method. Most states observed a major trade-off between determining asphalt content with the nuclear asphalt content gauge and determining aggregate gradation without vacuum extraction. Utah has opted to extract a sample at a reduced frequency exclusively for grading.

The comments section of the survey gave insight on how individual agencies respective views compared to one another. It appears that the agencies, who thoroughly researched the nuclear asphalt content gauge before implementation of their programs and who had an established plan of implementation, were more successful. Several agencies are still in this evaluation process. Other agencies are abandoning their programs, while some are expanding them.

FIGURE 2 WASHTO NUCLEAR SURVEY

STATE	DATE	DO YOU USE	EXCLU-SIVELY	FOR WHAT	BRAND	STANDARD COMPARED AGAINST	MOISTURE PROCEDURE	HOW CORRECTED FOR	GRADING	COMMENTS
ALASKA	11/17/87	YES	YES	ACCP	TROX	VAC EXTR	CONVECTION 300 F +/- 10 F 2 HR MINIMUM	1:1	COLD FEED SAME SUBLOT	The unions made us go to the nuclear gauge, because of the solvent hazardous situation. We used both Troxler and Campbell at one time, but the repair cost was to much to maintain both types. We use only Troxler gauges now.
ARIZONA	11/17/87	NO	NO	INFO	TROX	VAC EXTR				We experimented in the lab with the nuclear asphalt gauges in about 1982, and it was our recommendation not to implement a program at that time. We are not interested now, because we have so many different aggregate sources in our state. The City of Phoenix uses the nuclear gauges with good success.
CALIF.	11/03/87	YES	NO	ACCP	TROX	VAC EXTR	MICROWAVE	1:1	COLD FEED	We also allow two other methods, vacuum extraction and hot reflux. The major advantage is the potential increase in testing frequency. There also is a potential cost savings in running nuclear test over other methoods once the original capital outlay is funded.
COLO.	11/03/87	YES	YES	ACCP	TROX	VAC EXTR	AASHTO T-110	1:1	COLD FEED	We retain the vacuum extraction process in our central laboratory, because of the special mixes, RAP, rubberized, etc. Also, sometimes aggregate with a high mica content seems to adversely effect the nuclear gauge.
IDAHO	10/29/87	YES	NO	INFO ACCP	CAMP	TANK STICK	CONVECTION 230 F MICROWAVE	1:1	COLD FEED	We have purchased five Campbell nuclear gauges, and we entrusted the gauges to our field personnel. They have the option of using the gauges or not.
MONTANA	11/17/87	YES	NO	ACCP	TROX	TANK STICK	MICROWAVE OR CONVECTION	1:1	COLD FEED	We´ve had some difficulty on certain jobs, but overall nuclear gauges compare fairly well to the tank sticking for the days run. We started in 83 with our program, and we are now doing one vacuum extraction per five nuclear test. We have 17 gauges statewide.
NEVADA	11/17/87	YES	YES	ACCP	TROX	VAC EXTR	MICROWAVE	1:1	COLD FEED	We started our program in 82, and in 86 went exclusively to nuclear asphalt gauges. We allow 1.5% moisture in mix at point of testing behind paver. We perform a daily correction on a compacted dry sample. We implemented the use of a Hobart mixer that can handle 10,000 grams for producing calibration samples.
NEW MEXICO	11/17/87	YES	NO	INFO	TROX					We just purchased seven Troxler gauges, and I am setting up an evaluation program at this time. My goal is to remove the solvent from the field within two years.

STATE	DATE	DO YOU USE	EXCLU-SIVELY	FOR WHAT	BRAND	STANDARD COMPARED AGAINST	MOISTURE PROCEDURE	HOW CORRECTED FOR	GRADING	COMMENTS
NORTH DAKOTA	11/17/87	YES	NO	INFO ACCP	TROX	TANK STICK	CONVECTION CONSTANT WEIGHT	1:1	COLD FEED	We haven´t had much luck with our program, so we are quitting the use of nuclear asphalt gauges next season. Our major problem was with the accuracy of the gauges. Also, we were not confident in the gradation from the cold feed samples.
SOUTH DAKOTA	11/17/87	YES	NO	INFO	TROX CAMP	TANK STICK	MICROWAVE CONSTANT WEIGHT	1:1	NOT IMPORTANT	We believe that the nuclear asphalt gauge is a viable alternative to the vacuum extraction process. We allow up to 1.5% moisture in our mix that is processed in drum plants. Low levels of moisture in mix are conducive to good readings. We are not concerned about the grading.
TEXAS	11/03/87	YES	NO	INFO	TROX CAMP	VAC EXTR				It sounds like we are about where you are with your investigation. TDOT will have a report out in March or April. The center for Transportation Research will have a report out in January.
UTAH	11/18/87	YES	NO	INFO	TROX	VAC EXTR	MICROWAVE CONVECTION 350 F 1 Hr	1:1	VAC EXTR	We have studied this for 1 1/2 years, and we are confident that this is a viable program. I am setting up a field training program for this winter. We will purchase a gauge per project for the next 20 projects. We will run one vacuum extration per five nuclear tests. This extraction will be done with the new product line of degreasers, because we eliminated the chlorides. Also we will use the results from the grading of the vacuum extracted aggregate for acceptance on gradation.
WASH.	10/23/87	NO	NO							Our process control is performed by the contractor´s personnel, and since they can´t seem to get the license for operating the gauges. We do not use the nuclear asphalt gauge in our state.
WYOMING	11/17/87	YES	YES	ACCP	TROX	TANK STICK	WE DON´T		COLD FEED	We check one of every five nuclear asphalt samples with a split vacuum extracted sample. There is less variation in the nuclear than the vacuum extraction sample. Our correction for vacuum extraction is 200 F for 16 hrs. We pull a cold feed sample at the same frequency as the nuclear sample.
OREGON	11/17/87	YES	NO	INFO	CAMP	VAC EXTR KNOWN	MICROWAVE CONVECTION 325 F & 240 F	1:1	NONE	We experimented with the Troxler and Campbell nuclear gauges in the laboratory this summer. Presently we are performing additional testing with a Campbell gauge. Our goal is to make a recommendation to the construction section this winter about what to do in the upcoming construction season.
FHWA	11/18/87	NO	NO		TROX	VAC EXTR KNOWN	AASHTO T-110	1:1	COLD FEED	I am confident in the nuclear gauge program. It is unfortunate circumstances made us go away from them. We went exclusively to contractor process control, because of manpower. The contractor´s personnel have trouble with obtaining the proper license, and the initial cost is high. Transport of chemicals is becoming a major problem. It has been two years since we´ve used the nuclear gauge, but we retain the Troxler gauges in our office.

DESCRIPTION OF TEST PROGRAM

Basic knowledge of how the nuclear asphalt content gauge functions is helpful in understanding the work plan and test results. The following is a brief description on the theory of nuclear asphalt content gauges.

Theory of Nuclear Asphalt Content Gauge

The nuclear asphalt content gauge employs a neutron detector (Helium-3 or Boron Trifluoride) and a neutron emitter (Americium 241 and Beryllium 9) to detect hydrogen content through the principle of neutron moderation. This involves the reduction in neutron energy through collision with particles of similar mass. The resultant count of lower energy neutrons is analyzed quantitatively through the neutron detector system, which interprets this measurement as hydrogen ion content. The counts are related to an asphalt content by a calibration curve developed from samples of known asphalt content. When a sample of unknown asphalt content is tested, the gauge determines the hydrogen ion content, compares the result to the calibration curve, and displays the value for asphalt content percentage.

Precision and Accuracy of Nuclear Gauges

The precision of both the Troxler and Campbell gauges are claimed by the manufactures to be within the limits set in (ASTM D 4125-83). In this study, the precision of the Campbell nuclear asphalt content gauge was tested twice and was found to be within the ASTM limits.

The accuracy of both the Troxler and Campbell gauges was determined by performing a paired variate student t statistical analysis on the test results. The student t distribution is commonly used for small sample populations. A paired analysis was performed since split samples from different sublots of asphaltic concrete were tested. A more complete discussion of the statistical analysis follows.

The probability that t lies between two given values is determined by the appropriate area under the Student t-Distribution Curve. (Appendix D) The degrees of freedom are listed in the first column, and the t value corresponding to various two-tail areas are listed in the other columns. (8) For example, with 15 degrees of freedom, the t value corresponding to a confidence value of 0.05 for the two-tail area equals 2.131. This means that the probability of obtaining a mean difference between two sample populations by chance with a Student t-statistic between 2.131 or -2.131 (15 degrees of freedom) is equal to 0.05 (5 percent).

Phase I - Field Bituminous Mixture Evaluation

The evaluation of the nuclear asphalt content gauges began during the summer of 1987. A project near the Materials and Research Laboratory was selected. This was 12th Street SE to 24th Street SE, Mission Street (Salem) Project. A class "B" mix (3/4-inch nominal maximum aggregate size) was used. (Appendix E)

The asphaltic concrete mixture was sampled from the back of the truck at the batch plant, placed in a five gallon container, and transported to the Materials Laboratory for testing. The trip took five to ten minutes. In the laboratory, material was quartered into four equal test samples. Two 7000 gram samples were made for the Troxler and Campbell nuclear gauges. The remainder of the material was used to determine moisture content. (Appendix A)

One 7000 gram sample was tested in the Troxler gauge, while the other was tested in the Campbell gauge. Four, four-minute tests were run in each gauge. At the end of this time, the samples were switched between the gauges and tested again. After the nuclear testing was completed, the samples were vacuum extracted. The sample that was tested in the Troxler gauge first was sent to the field lab for vacuum extraction, while the other sample was extracted in the Materials and Research Laboratory.

From the remainder of the AC mix, five moisture samples were prepared. One 1000 gm. sample was tested for moisture content by (OSHD TM 311(M)-86). (Appendix G) This is Oregon's microwave procedure for moisture determination. Two samples were tested by (OSHD TM 311(O)-86). (Appendix F) This is Oregon's convection oven procedure, 230° F oven for 24 hours. Two samples were placed in a 325° F oven for 24 hours. This is not an accepted OSHD drying procedure, but was performed to develop a correlation.

Additional questions arose from the testing of the AC mixture which needed further study before conclusions could be reached. These included:

1) What is the amount of actual moisture in the mix?
2) How does retention of asphalt in the aggregate affect the result?
3) What is the actual asphalt content in the AC mixture?

The second phase of this study was continued in the Materials and Research Laboratory, where these questions could be answered.

Phase II - Laboratory Fabricated Samples Evaluation

Since there were so many variables in the field samples, it was decided that test samples should be fabricated under controlled laboratory conditions. Some of the unknowns were; moisture that was contained within the rock and amount of asphalt actually in the mix. To control these conditions, the amount of asphalt added to the samples was carefully measured and controlled. The amount of moisture was determined by careful weighing all materials during mixing and by performing a mass balance analysis to track the amount of moisture absorbed over time.

Calibration samples were prepared to known asphalt contents, 5% and 7%, with all moisture being closely tracked. (Appendix B) The test samples were prepared consistent with the calibration procedure, but the asphalt contents were varied randomly. Once prepared the test samples were analyzed in the Campbell AC-2 gauge. The instrument was programed for four, four-minute counts. It was determined that both calibration samples and test samples absorbed moisture ranging from 0.08% to 0.14%. Since this is a narrow range no correction for moisture was applied.

TEST RESULTS

The results of the individual analyses are reported in Tables 1 thru 25, and the results are summarized in Table 28 & 29.

Effects of Moisture Correction

The first comparison, Category 1, samples evaluated were tested first in the Troxler gauge and second in the Campbell gauge. Data is shown for three different moisture conditions (uncorrected), corrected using (OSHD TM 311(O)-86), and corrected using (325° F Oven). In each, the nuclear gauges were compared to the laboratory vacuum extraction corrected by (OSHD TM 311(O)-86). The mean difference for all comparisons in Category 1 were statistically significant. The t statistic ranged from -11.154 to -3.148, which is an absolute value greater than the t-critical value of 2.093. The mean difference for percent asphalt content ranged from -0.67% to 0.25%.

Category 2 results are similar to Category 1 except the sample order is reversed. The samples evaluated were tested first in the Campbell and then in the Troxler. Again, the mean difference for all comparisons were statistically significant, with the t statistic ranging from -12.912 to -2.741. These values exceed t-critical of 2.093.

Category 3 results are the average values obtained from combining Categories 1 & 2. Once again, all comparisons were statistically significant. The t statistic ranged from -12.936 to 2.923, which is compared to the same value for t-critical as in the previous categories.

The results for all three categories of tests show the significance of moisture content to the asphalt content determination by the nuclear gauge. With no correction for moisture content, the nuclear gauge asphalt content is about 0.6 percent higher than the referee procedure (vacuum extraction corrected for moisture content using (OSHD TM 311(O)-86). When corrected using moisture contents determined by (OSHD TM 311(O)-86), the nuclear gauge asphalt content is about 0.3 percent higher than the referee procedure. Finally, when corrected using moisture contents determined by heating in a 325° F oven, the nuclear gauge asphalt content is still about 0.2 percent higher than the referee procedure.

These results show the potential error in nuclear gauge asphalt content if moisture is not corrected appropriately. They also show that approximately 0.1 percent moisture remains in the AC mixture when (OSHD TM 311(O)-86) is used. Finally, the 0.2 percent residual difference may be due to retention of asphalt in the aggregate, since the difference is similar in amount to retention values determined in other studies.

Comparison of Nuclear Gauges and Vacuum Procedures

Category 4 compared the two vacuum extraction analyses against each other, Tables 19 & 20. The two nuclear gauge analyses are in Tables 21, 22, & 23. Table 19 compares the field vacuum extractions (OSHD TM 311(M)-86) to laboratory vacuum extractions (OSHD TM 311(O)-86) Tables 21, 22, & 23 compare the Troxler gauge results and the Campbell gauge results. Tables 19 & 23 exhibited statistically significant mean differences, while Tables 20, 21, & 22 did not. The respective t statistic values for Tables 20, 21, & 22 were -0.7794, -0.6621, & -1.7932.

The results in Table 19 show a significant mean difference between field vacuum extraction results obtained with microwave drying and laboratory vacuum extraction results with standard oven drying. The mean difference is about 0.2 percent asphalt. These results show the potential error that can occur if either nuclear gauge or vacuum extraction asphalt contents are not adjusted for moisture appropriately.

The results in Table 20 show no significant difference between field vacuum extractions and laboratory vacuum extractions when both are obtained using microwave drying. The mean difference is quite small, 0.04 percent. This confirms that both methods produce essentially the same results if the same method of drying is used.

The results in Table 21 show no significant difference in asphalt contents determined by the Troxler gauge (uncorrected for moisture content) when comparing the samples which were tested first in the Troxler gauge against the samples which were tested first in the Campbell gauge. This shows good precision (0.03 mean difference) in Troxler gauge results.

The results in Table 22, while not significant at the 95% confidence level, are significant at the 90% confidence level. They indicate a mean difference of about 0.10 percent in asphalt contents determined by the Campbell gauge when comparing the samples which were tested first in the Troxler gauge against the samples which were tested first in the Campbell gauge. The only variable which might account for this difference is the fan in the Troxler gauge, which cools the mixture during testing. The data may indicate an inability of the Campbell gauge to totally compensate for sample temperature changes. While moisture differences between the two samples could be suspected, the lack of a similar difference in the Troxler gauge results points toward a source of error in the Campbell gauge.

The results in Table 23 show a small (0.05 percent mean difference) but statistically significant difference in the asphalt contents determined by the Troxler and Campbell nuclear gauges. While this difference is within the same range as the

difference in asphalt content determined by field vacuum extraction and laboratory vacuum extraction (see Table 20), the statistically significant difference indicates a relatively high level of precision for both gauges. It also indicates a small but systematic error which may be due to differences in gauge calibrations.

Comparison of Nuclear Gauge Results vs. Known Asphalt Content

The final analysis, Category 5 compared the nuclear gauge and vacuum extraction results against a known asphalt content. In both cases, there was a statistically significant difference in the results. The t-statistic for the Campbell vs. known asphalt content comparison was 4.4783 and for the vacuum extraction vs. known asphalt content comparison was 6.5433. Since the sample population varied in the two comparisons, the t-critical value differed, 2.110 and 2.064 respectively. The mean difference for percent asphalt in the Campbell gauge comparison was 0.13%, and 0.16% in the vacuum extraction comparison.

The results in Table 24 show a significant mean difference between the Campbell nuclear gauge results (uncorrected for moisture) and the known asphalt content (with some moisture present). The mean difference is about 0.13 percent, with the nuclear gauge results lower than the known asphalt content. No moisture correction was made, since the moisture content in all samples was carefully controlled during fabrication and similar amounts of moisture were contained in both the test samples and the calibration samples. While there is no clear explanation for the difference, it may be that the nuclear gauge content on one of the calibration samples was slightly atypical, resulting in a systematic error on all other tests. These results do show the potential for systematic or random errors using the nuclear gauge, possibly as a result the statistical nature of the radiation source.

The results in Table 25 show a significant mean difference between the vacuum extraction results corrected for moisture by (OSHD 311(M)-86) and the known asphalt content. The mean difference is about 0.16 percent, with the vacuum extraction results lower than the known asphalt content. If (OSHD TM 311(O)-86) had been used to dry the aggregate, a lower asphalt content up to 0.2%, (see Table 19) would have been determined. The resultant difference of about 0.36 percent could be attributed to retention in the aggregate.

In summary, the Category 5 results indicate that while the nuclear gauge has some inherent error, the accuracy is similar to those obtained by vacuum extraction using microwave drying.

CONCLUSIONS

1) The nuclear asphalt content gauge is a precise and accurate instrument when properly used. Proper calibration is essential and tests results must be corrected for moisture content. It can be a useful tool to determine the asphalt content of virgin asphaltic concrete mixtures.

2) Within the range of 0.0% - 1.5% moisture, the nuclear asphalt content gauge measures moisture linearly, as it would asphalt. Therefore, an accurate, but rapid test is needed to determine moisture content of AC samples. Within this range moisture corrections may be made by subtracting the moisture content directly from the nuclear gauge reading on a 1:1 basis. Moisture corrections are important to both the nuclear gauge and vacuum extraction methods, therefore the net effect on measured asphalt content accuracy would be the same.

3) When comparing the vacuum extractor results to the nuclear gauge, the absorbed asphalt in the aggregate is not identified with the vacuum method, whereas the nuclear gauge will count the hydrogen ions of asphalt absorbed within aggregate. The nuclear gauge is a more precise and accurate method of measurement since it is not sensitive to asphalt retention.

4) When using the nuclear asphalt content gauge, the aggregate gradation needs to be determined by some other method. This is the greatest obstacle to immediately substituting the nuclear gauge method for the vacuum extraction method.

5) Since recycled asphalt concrete pavement (RAP) is being used in many jobs, the investigation of nuclear gauge accuracy with RAP is needed before the gauge could be used on all projects.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are suggested for implementation:

1) Conduct additional studies to determine the accuracy and precision of the mixture with RAP included, and to develop a testing procedure which could be used both in the laboratory and in the field.

2) Further evaluate the nuclear gauge on selected projects as an asphalt content job control test device.

   At the same time, use the vacuum extraction method for determining asphalt content pay factors. This will provide comparison of the two methods under field conditions.

3) Adopt an oven dry moisture test to correct for moisture in nuclear test data.

4) Develop an alternate method to determine the aggregate gradation of the mixture at the point of final placement. This could include vacuum extraction with non-toxic solvents, a combination of frequent cold-feed testing with less frequent vacuum extractions, or other methods.

5) Begin to develop a planning, training, and funding program with the objective of using nuclear gauges to determine asphalt content in the 1989 or 1990 construction season. This task would likely be undertaken by the Construction Section.

LIST OF TABLES

13. Troxler Nuclear Gauge (uncorrected) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

14. Campbell Nuclear Gauge (uncorrected) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

15. Troxler Nuclear gauge (TM 311 (O)-86) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

16. Campbell Nuclear Gauge (TM 311 (O)-86) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

17. Troxler Nuclear Gauge (Oven @ 325° F) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

18. Campbell Nuclear Gauge (Oven @ 325° F) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

(3) Sample Values Are Average

19. Field Vacuum Extraction (TM 311 (M)-86) vs. Laboratory Vacuum Extraction (TM 311 (O)-86)

20. Field Vacuum Extraction (TM 311 (M)-86) vs. Laboratory Vacuum Extraction (TM 311 (M)-86)

21. Troxler Nuclear Gauge (A) (uncorrected) vs. Troxler Nuclear Gauge (B) (uncorrected)

22. Campbell Nuclear Gauge (A) (uncorrected) vs. Campbell Nuclear Gauge (B) (uncorrected)

23. Troxler Nuclear Gauge (uncorrected) vs. Campbell Nuclear Gauge (uncorrected)

(4) Vacuum vs. Vacuum and Nuclear vs. Nuclear

24. Campbell Nuclear Gauge (uncorrected) vs. Known Asphalt Content (uncorrected)

25. Laboratory Vacuum Extraction (TM 311 (M)-86) vs. Known Asphalt Content (uncorrected)

(5) Nuclear and Vacuum vs. Known

26. Precision of Campbell Nuclear Gauge

27. Precision of Campbell Nuclear Gauge

28. Summary Table

29. Summary Table

TABLE 1

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected	Corrected by TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.41	5.70	-0.71	-0.67	-0.04	0.00	0.26	0.06	-11.1543
2	6.72	6.10	-0.62		0.05	0.00			
3	6.57	5.80	-0.77		-0.10	0.01			
4	6.39	6.00	-0.39		0.28	0.08			
5	6.58	5.70	-0.88		-0.21	0.05			
6	6.63	5.90	-0.73		-0.06	0.00			
7	6.23	5.80	-0.43		0.24	0.06			
8	6.21	5.80	-0.41		0.26	0.07			
9	6.30	5.60	-0.70		-0.03	0.00			
10	5.50	4.90	-0.60		0.07	0.00			
11	5.66	5.50	-0.16		0.51	0.26			
12	5.96	5.40	-0.56		0.11	0.01			
13	5.56	5.30	-0.26		0.41	0.16			
14	6.13	5.30	-0.83		-0.16	0.03			
15	6.33	5.30	-1.03		-0.36	0.13			
16	6.63	5.50	-1.13		-0.46	0.22			
17	6.44	5.40	-1.04		-0.37	0.14			
18	5.97	5.30	-0.67		0.00	0.00			
19	6.03	5.30	-0.73		-0.06	0.00			

TABLE 2

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected	Corrected by TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.44	5.70	-0.74	-0.66	-0.08	0.01	0.34	0.08	-8.4573
2	6.76	6.10	-0.66		0.00	0.00			
3	6.49	5.80	-0.69		-0.03	0.00			
4	6.29	6.00	-0.29		0.37	0.13			
5	6.54	5.70	-0.84		-0.18	0.03			
6	6.40	5.90	-0.50		0.16	0.02			
7	6.06	5.80	-0.26		0.40	0.16			
8	6.27	5.80	-0.47		0.19	0.03			
9	6.37	5.60	-0.77		-0.11	0.01			
10	5.53	4.90	-0.63		0.03	0.00			
11	5.44	5.50	0.06		0.72	0.51			
12	5.81	5.40	-0.41		0.25	0.06			
13	5.56	5.30	-0.26		0.40	0.16			
14	6.13	5.30	-0.83		-0.17	0.03			
15	6.27	5.30	-0.97		-0.31	0.10			
16	6.79	5.50	-1.29		-0.63	0.40			
17	6.62	5.40	-1.22		-0.56	0.32			
18	6.15	5.30	-0.85		-0.19	0.04			
19	6.15	5.30	-0.85		-0.19	0.04			

TABLE 3

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction
Corrected by TM 311(O)-86 Corrected by TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.17	5.70	-0.47	-0.37	-0.10	0.01	0.28	0.06	-5.7762
2	6.26	6.10	-0.16		0.21	0.04			
3	6.39	5.80	-0.59		-0.22	0.05			
4	5.98	6.00	0.02		0.39	0.15			
5	6.11	5.70	-0.41		-0.04	0.00			
6	6.34	5.90	-0.44		-0.07	0.00			
7	5.93	5.80	-0.13		0.24	0.06			
8	5.98	5.80	-0.18		0.19	0.04			
9	5.98	5.60	-0.38		-0.01	0.00			
10	5.29	4.90	-0.39		-0.02	0.00			
11	5.35	5.50	0.15		0.52	0.27			
12	5.65	5.40	-0.25		0.12	0.01			
13	5.31	5.30	-0.01		0.36	0.13			
14	5.77	5.30	-0.47		-0.10	0.01			
15	5.91	5.30	-0.61		-0.24	0.06			
16	6.36	5.50	-0.86		-0.49	0.24			
17	6.32	5.40	-0.92		-0.55	0.30			
18	5.72	5.30	-0.42		-0.05	0.00			
19	5.80	5.30	-0.50		-0.13	0.02			

TABLE 4

CAMPBELL Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by TM 311(O)-86	Corrected by TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.20	5.70	-0.50	-0.35	-0.15	0.02	0.33	0.08	-4.6459
2	6.30	6.10	-0.20		0.15	0.02			
3	6.31	5.80	-0.51		-0.16	0.02			
4	5.88	6.00	0.12		0.47	0.23			
5	6.07	5.70	-0.37		-0.02	0.00			
6	6.11	5.90	-0.21		0.14	0.02			
7	5.76	5.80	0.04		0.39	0.16			
8	6.04	5.80	-0.24		0.11	0.01			
9	6.05	5.60	-0.45		-0.10	0.01			
10	5.32	4.90	-0.42		-0.07	0.00			
11	5.23	5.50	0.27		0.62	0.39			
12	5.50	5.40	-0.10		0.25	0.06			
13	5.31	5.30	-0.01		0.34	0.12			
14	5.77	5.30	-0.47		-0.12	0.01			
15	5.85	5.30	-0.55		-0.20	0.04			
16	6.52	5.50	-1.02		-0.67	0.44			
17	6.30	5.40	-0.90		-0.55	0.30			
18	5.90	5.30	-0.60		-0.25	0.06			
19	5.92	5.30	-0.62		-0.27	0.07			

TABLE 5

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by 325 F Oven	Corrected by TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.17	5.70	-0.47	-0.26	-0.21	0.04	0.29	0.07	-4.0107
2	6.26	6.10	-0.16		0.10	0.01			
3	6.18	5.80	-0.38		-0.12	0.01			
4	5.96	6.00	0.04		0.30	0.09			
5	6.12	5.70	-0.42		-0.16	0.02			
6	6.09	5.90	-0.19		0.07	0.01			
7	5.74	5.80	0.06		0.32	0.10			
8	5.85	5.80	-0.05		0.21	0.05			
9	5.82	5.60	-0.22		0.04	0.00			
10	5.03	4.90	-0.13		0.13	0.02			
11	5.22	5.50	0.28		0.54	0.30			
12	5.58	5.40	-0.18		0.08	0.01			
13	5.20	5.30	0.10		0.36	0.13			
14	5.73	5.30	-0.43		-0.17	0.03			
15	5.85	5.30	-0.55		-0.29	0.08			
16	6.20	5.50	-0.70		-0.44	0.19			
17	6.26	5.40	-0.86		-0.60	0.36			
18	5.66	5.30	-0.36		-0.10	0.01			
19	5.68	5.30	-0.38		-0.12	0.01			

TABLE 6

CAMPBELL Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by	Corrected by
325 F Oven	TM 311(O)-86

SAMPLE ORDER TROXLER TO CAMPBELL

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.20	5.70	-0.50	-0.25	-0.25	0.06	0.34	0.08	-3.1475
2	6.30	6.10	-0.20		0.05	0.00			
3	6.10	5.80	-0.30		-0.05	0.00			
4	5.86	6.00	0.14		0.39	0.15			
5	6.08	5.70	-0.38		-0.13	0.02			
6	5.86	5.90	0.04		0.29	0.08			
7	5.57	5.80	0.23		0.48	0.23			
8	5.91	5.80	-0.11		0.14	0.02			
9	5.89	5.60	-0.29		-0.04	0.00			
10	5.06	4.90	-0.16		0.09	0.01			
11	5.10	5.50	0.40		0.65	0.42			
12	5.43	5.40	-0.03		0.22	0.05			
13	5.20	5.30	0.10		0.35	0.12			
14	5.73	5.30	-0.43		-0.18	0.03			
15	5.79	5.30	-0.49		-0.24	0.06			
16	6.36	5.50	-0.86		-0.61	0.37			
17	6.24	5.40	-0.84		-0.59	0.35			
18	5.84	5.30	-0.54		-0.29	0.09			
19	5.80	5.30	-0.50		-0.25	0.06			

TABLE 7

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected	Corrected by TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.21	5.70	-0.51	-0.64	0.13	0.02	0.22	0.05	-12.9117
2	6.65	6.10	-0.55		0.09	0.01			
3	6.39	5.80	-0.59		0.05	0.00			
4	6.37	6.00	-0.37		0.27	0.07			
5	6.42	5.70	-0.72		-0.08	0.01			
6	6.59	5.90	-0.69		-0.05	0.00			
7	6.28	5.80	-0.48		0.16	0.03			
8	6.40	5.80	-0.60		0.04	0.00			
9	6.09	5.60	-0.49		0.15	0.02			
10	5.34	4.90	-0.44		0.20	0.04			
11	5.96	5.50	-0.46		0.18	0.03			
12	5.98	5.40	-0.58		0.06	0.00			
13	5.93	5.30	-0.63		0.01	0.00			
14	6.12	5.30	-0.82		-0.18	0.03			
15	6.25	5.30	-0.95		-0.31	0.10			
16	6.82	5.50	-1.32		-0.68	0.46			
17	6.08	5.40	-0.68		-0.04	0.00			
18	5.86	5.30	-0.56		0.08	0.01			
19	6.01	5.30	-0.71		-0.07	0.00			

TABLE 8

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected — Corrected by TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.26	5.70	-0.56	-0.56	0.00	0.00	0.26	0.06	-9.2515
2	6.40	6.00	-0.40		0.16	0.02			
3	6.32	5.80	-0.52		0.04	0.00			
4	6.44	5.70	-0.74		-0.18	0.03			
5	6.43	5.70	-0.73		-0.17	0.03			
6	6.36	5.90	-0.46		0.10	0.01			
7	6.13	5.80	-0.33		0.23	0.05			
8	6.19	5.80	-0.39		0.17	0.03			
9	6.10	5.60	-0.50		0.06	0.00			
10	5.21	4.90	-0.31		0.25	0.06			
11	5.70	5.50	-0.20		0.36	0.13			
12	6.01	5.40	-0.61		-0.05	0.00			
13	5.68	5.30	-0.38		0.18	0.03			
14	5.95	5.30	-0.65		-0.09	0.01			
15	6.26	5.30	-0.96		-0.40	0.16			
16	6.86	5.50	-1.36		-0.80	0.65			
17	5.93	5.40	-0.53		0.03	0.00			
18	5.79	5.30	-0.49		0.07	0.00			
19	5.75	5.30	-0.45		0.11	0.01			

TABLE 9

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction
Corrected by TM 311(O)-86 Corrected by TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	5.97	5.70	-0.27	-0.36	0.09	0.01	0.20	0.05	-7.9274
2	6.19	6.00	-0.19		0.17	0.03			
3	6.21	5.80	-0.41		-0.05	0.00			
4	5.96	5.70	-0.26		0.10	0.01			
5	5.95	5.70	-0.25		0.11	0.01			
6	6.30	5.90	-0.40		-0.04	0.00			
7	5.98	5.80	-0.18		0.18	0.03			
8	6.17	5.80	-0.37		-0.01	0.00			
9	5.77	5.60	-0.17		0.19	0.04			
10	5.13	4.90	-0.23		0.13	0.02			
11	5.75	5.50	-0.25		0.11	0.01			
12	5.67	5.40	-0.27		0.09	0.01			
13	5.68	5.30	-0.38		-0.02	0.00			
14	5.76	5.30	-0.46		-0.10	0.01			
15	5.83	5.30	-0.53		-0.17	0.03			
16	6.55	5.50	-1.05		-0.69	0.48			
17	5.76	5.40	-0.36		0.00	0.00			
18	5.61	5.30	-0.31		0.05	0.00			
19	5.78	5.30	-0.48		-0.12	0.01			

TABLE 10

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction
Corrected by TM 311(O)-86 Corrected by TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.02	5.70	-0.32	-0.27	-0.05	0.00	0.24	0.05	-4.8671
2	5.94	6.00	0.06		0.33	0.11			
3	6.14	5.80	-0.34		-0.07	0.01			
4	6.03	5.70	-0.33		-0.06	0.00			
5	5.96	5.70	-0.26		0.01	0.00			
6	6.07	5.90	-0.17		0.10	0.01			
7	5.83	5.80	-0.03		0.24	0.06			
8	5.96	5.80	-0.16		0.11	0.01			
9	5.78	5.60	-0.18		0.09	0.01			
10	5.00	4.90	-0.10		0.17	0.03			
11	5.69	5.50	-0.19		0.08	0.01			
12	5.70	5.40	-0.30		-0.03	0.00			
13	5.43	5.30	-0.13		0.14	0.02			
14	5.59	5.30	-0.29		-0.02	0.00			
15	5.84	5.30	-0.54		-0.27	0.08			
16	6.59	5.50	-1.09		-0.82	0.68			
17	5.61	5.40	-0.21		0.06	0.00			
18	5.54	5.30	-0.24		0.03	0.00			
19	5.52	5.30	-0.22		0.05	0.00			

TABLE 11

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by Oven @ 325 F	Corrected by TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	5.97	5.70	-0.27	-0.25	-0.02	0.00	0.20	0.05	-5.4253
2	6.19	6.00	-0.19		0.06	0.00			
3	6.00	5.80	-0.20		0.05	0.00			
4	5.94	5.70	-0.24		0.01	0.00			
5	5.96	5.70	-0.26		-0.01	0.00			
6	6.05	5.90	-0.15		0.10	0.01			
7	5.79	5.80	0.01		0.26	0.07			
8	6.04	5.80	-0.24		0.01	0.00			
9	5.61	5.60	-0.01		0.24	0.06			
10	4.87	4.90	0.03		0.28	0.08			
11	5.62	5.50	-0.12		0.13	0.02			
12	5.60	5.40	-0.20		0.05	0.00			
13	5.57	5.30	-0.27		-0.02	0.00			
14	5.72	5.30	-0.42		-0.17	0.03			
15	5.77	5.30	-0.47		-0.22	0.05			
16	6.39	5.50	-0.89		-0.64	0.41			
17	5.70	5.40	-0.30		-0.05	0.00			
18	5.55	5.30	-0.25		0.00	0.00			
19	5.66	5.30	-0.36		-0.11	0.01			

TABLE 12

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by	Corrected by
Oven @ 325 F	TM 311(O)-86

SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.02	5.70	-0.32	-0.16	-0.16	0.03	0.25	0.06	-2.7406
2	5.94	6.00	0.06		0.22	0.05			
3	5.93	5.80	-0.13		0.03	0.00			
4	6.01	5.70	-0.31		-0.15	0.02			
5	5.97	5.70	-0.27		-0.11	0.01			
6	5.82	5.90	0.08		0.24	0.06			
7	5.64	5.80	0.16		0.32	0.10			
8	5.83	5.80	-0.03		0.13	0.02			
9	5.62	5.60	-0.02		0.14	0.02			
10	4.74	4.90	0.16		0.32	0.10			
11	5.56	5.50	-0.06		0.10	0.01			
12	5.63	5.40	-0.23		-0.07	0.01			
13	5.32	5.30	-0.02		0.14	0.02			
14	5.55	5.30	-0.25		-0.09	0.01			
15	5.78	5.30	-0.48		-0.32	0.10			
16	6.43	5.50	-0.93		-0.77	0.59			
17	5.55	5.40	-0.15		0.01	0.00			
18	5.48	5.30	-0.18		-0.02	0.00			
19	5.40	5.30	-0.10		0.06	0.00			

TABLE 13

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected	Corrected by TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.31	5.70	-0.61	-0.65	0.04	0.00	0.22	0.05	-12.9363
2	6.69	6.10	-0.59		0.06	0.00			
3	6.48	5.80	-0.68		-0.03	0.00			
4	6.38	6.00	-0.38		0.27	0.08			
5	6.50	5.70	-0.80		-0.15	0.02			
6	6.61	5.90	-0.71		-0.06	0.00			
7	6.26	5.80	-0.46		0.19	0.04			
8	6.31	5.80	-0.51		0.14	0.02			
9	6.20	5.60	-0.60		0.05	0.00			
10	5.42	4.90	-0.52		0.13	0.02			
11	5.81	5.50	-0.31		0.34	0.12			
12	5.97	5.40	-0.57		0.08	0.01			
13	5.75	5.30	-0.45		0.20	0.04			
14	6.13	5.30	-0.83		-0.18	0.03			
15	6.29	5.30	-0.99		-0.34	0.11			
16	6.73	5.50	-1.23		-0.58	0.33			
17	6.26	5.40	-0.86		-0.21	0.04			
18	5.92	5.30	-0.62		0.03	0.00			
19	6.02	5.30	-0.72		-0.07	0.00			

TABLE 14

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Uncorrected	Corrected by TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.35	5.70	-0.65	-0.60	-0.05	0.00	0.28	0.06	-9.3438
2	6.58	6.10	-0.48		0.12	0.01			
3	6.41	5.80	-0.61		-0.01	0.00			
4	6.37	6.00	-0.37		0.23	0.05			
5	6.49	5.70	-0.79		-0.19	0.04			
6	6.38	5.90	-0.48		0.12	0.01			
7	6.10	5.80	-0.30		0.30	0.09			
8	6.23	5.80	-0.43		0.17	0.03			
9	6.24	5.60	-0.64		-0.04	0.00			
10	5.37	4.90	-0.47		0.13	0.02			
11	5.57	5.50	-0.07		0.53	0.28			
12	5.91	5.40	-0.51		0.09	0.01			
13	5.62	5.30	-0.32		0.28	0.08			
14	6.04	5.30	-0.74		-0.14	0.02			
15	6.27	5.30	-0.97		-0.37	0.14			
16	6.83	5.50	-1.33		-0.73	0.54			
17	6.28	5.40	-0.88		-0.28	0.08			
18	5.97	5.30	-0.67		-0.07	0.01			
19	5.95	5.30	-0.65		-0.05	0.00			

TABLE 15

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by TM 311(O)-86	Corrected by TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.07	5.70	-0.37	-0.35	-0.02	0.00	0.22	0.05	-7.0739
2	6.23	6.10	-0.13		0.22	0.05			
3	6.30	5.80	-0.50		-0.15	0.02			
4	5.97	6.00	0.03		0.38	0.15			
5	6.03	5.70	-0.33		0.02	0.00			
6	6.32	5.90	-0.42		-0.07	0.00			
7	5.96	5.80	-0.16		0.19	0.04			
8	6.08	5.80	-0.28		0.07	0.01			
9	5.88	5.60	-0.28		0.07	0.01			
10	5.21	4.90	-0.31		0.04	0.00			
11	5.60	5.50	-0.10		0.25	0.06			
12	5.66	5.40	-0.26		0.09	0.01			
13	5.50	5.30	-0.20		0.15	0.02			
14	5.77	5.30	-0.47		-0.12	0.01			
15	5.87	5.30	-0.57		-0.22	0.05			
16	6.46	5.50	-0.96		-0.61	0.37			
17	5.94	5.40	-0.54		-0.19	0.03			
18	5.67	5.30	-0.37		-0.02	0.00			
19	5.79	5.30	-0.49		-0.14	0.02			

TABLE 16

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by TM 311(O)-86	Corrected by TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.11	5.70	-0.41	-0.30	-0.11	0.01	0.27	0.06	-4.7504
2	6.12	6.10	-0.02		0.28	0.08			
3	6.23	5.80	-0.43		-0.13	0.02			
4	5.96	6.00	0.04		0.34	0.11			
5	6.02	5.70	-0.32		-0.02	0.00			
6	6.09	5.90	-0.19		0.11	0.01			
7	5.80	5.80	0.00		0.30	0.09			
8	6.00	5.80	-0.20		0.10	0.01			
9	5.92	5.60	-0.32		-0.02	0.00			
10	5.16	4.90	-0.26		0.04	0.00			
11	5.36	5.50	0.14		0.44	0.19			
12	5.60	5.40	-0.20		0.10	0.01			
13	5.37	5.30	-0.07		0.23	0.05			
14	5.68	5.30	-0.38		-0.08	0.01			
15	5.85	5.30	-0.55		-0.25	0.06			
16	6.56	5.50	-1.06		-0.76	0.58			
17	5.96	5.40	-0.56		-0.26	0.07			
18	5.75	5.30	-0.45		-0.15	0.02			
19	5.72	5.30	-0.42		-0.12	0.01			

TABLE 17

Troxler Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by	Corrected by
325 F Oven	TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.07	5.70	-0.37	-0.25	-0.12	0.02	0.22	0.05	-4.9196
2	6.23	6.10	-0.13		0.12	0.01			
3	6.09	5.80	-0.29		-0.04	0.00			
4	5.95	6.00	0.05		0.30	0.09			
5	6.04	5.70	-0.34		-0.09	0.01			
6	6.07	5.90	-0.17		0.08	0.01			
7	5.77	5.80	0.03		0.28	0.08			
8	5.95	5.80	-0.15		0.10	0.01			
9	5.72	5.60	-0.12		0.13	0.02			
10	4.95	4.90	-0.05		0.20	0.04			
11	5.47	5.50	0.03		0.28	0.08			
12	5.59	5.40	-0.19		0.06	0.00			
13	5.39	5.30	-0.09		0.16	0.02			
14	5.73	5.30	-0.43		-0.18	0.03			
15	5.81	5.30	-0.51		-0.26	0.07			
16	6.30	5.50	-0.80		-0.55	0.31			
17	5.88	5.40	-0.48		-0.23	0.05			
18	5.61	5.30	-0.31		-0.06	0.00			
19	5.67	5.30	-0.37		-0.12	0.02			

TABLE 18

Campbell Nuclear Gauge vs. Laboratory Vacuum Extraction

Corrected by 325 F Oven	Corrected by TM 311(O)-86

SAMPLE VALUES ARE AVERAGE

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.11	5.70	-0.41	-0.19	-0.22	0.05	0.28	0.06	-2.9277
2	6.12	6.10	-0.02		0.17	0.03			
3	6.02	5.80	-0.22		-0.03	0.00			
4	5.94	6.00	0.06		0.25	0.06			
5	6.03	5.70	-0.33		-0.14	0.02			
6	5.84	5.90	0.06		0.25	0.06			
7	5.61	5.80	0.19		0.38	0.14			
8	5.87	5.80	-0.07		0.12	0.01			
9	5.76	5.60	-0.16		0.03	0.00			
10	4.90	4.90	0.00		0.19	0.04			
11	5.23	5.50	0.27		0.46	0.21			
12	5.53	5.40	-0.13		0.06	0.00			
13	5.26	5.30	0.04		0.23	0.05			
14	5.64	5.30	-0.34		-0.15	0.02			
15	5.79	5.30	-0.49		-0.30	0.09			
16	6.40	5.50	-0.90		-0.71	0.50			
17	5.90	5.40	-0.50		-0.31	0.10			
18	5.66	5.30	-0.36		-0.17	0.03			
19	5.60	5.30	-0.30		-0.11	0.01			

TABLE 19

Field Vacuum Extraction vs. Laboratory Vacuum Extraction
Corrected by TM 311(M)-86 Corrected by TM 311(O)-86

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.00	5.70	-0.30	-0.21	-0.09	0.01	0.21	0.05	-4.3586
2	6.30	6.00	-0.30		-0.09	0.01			
3	6.20	5.80	-0.40		-0.19	0.04			
4	6.00	5.70	-0.30		-0.09	0.01			
5	6.10	5.70	-0.40		-0.19	0.04			
6	6.10	5.90	-0.20		0.01	0.00			
7	5.90	5.80	-0.10		0.11	0.01			
8	5.90	5.80	-0.10		0.11	0.01			
9	5.80	5.60	-0.20		0.01	0.00			
10	5.10	4.90	-0.20		0.01	0.00			
11	5.20	5.50	0.30		0.51	0.26			
12	5.60	5.40	-0.20		0.01	0.00			
13	5.30	5.30	0.00		0.21	0.04			
14	5.80	5.30	-0.50		-0.29	0.08			
15	5.90	5.30	-0.60		-0.39	0.15			
16	5.50	5.50	0.00		0.21	0.04			
17	5.80	5.40	-0.40		-0.19	0.04			
18	5.40	5.30	-0.10		0.11	0.01			
19	5.30	5.30	0.00		0.21	0.04			

TABLE 20

Field Vacuum Extrtaction vs. Laboratory Vacuum Extraction
Corrected by TM 311(M)-86 Corrected by TM 311(M)-86

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.00	5.90	-0.10	-0.04	-0.06	0.00	0.21	0.05	-0.7794
2	6.30	6.20	-0.10		-0.06	0.00			
3	6.20	5.80	-0.40		-0.36	0.13			
4	6.00	6.00	0.00		0.04	0.00			
5	6.10	5.90	-0.20		-0.16	0.03			
6	6.10	6.10	0.00		0.04	0.00			
7	5.90	5.90	0.00		0.04	0.00			
8	5.90	5.90	0.00		0.04	0.00			
9	5.80	5.80	0.00		0.04	0.00			
10	5.10	5.00	-0.10		-0.06	0.00			
11	5.20	5.60	0.40		0.44	0.19			
12	5.60	5.60	0.00		0.04	0.00			
13	5.30	5.40	0.10		0.14	0.02			
14	5.80	5.50	-0.30		-0.26	0.07			
15	5.90	5.50	-0.40		-0.36	0.13			
16	5.50	5.70	0.20		0.24	0.06			
17	5.80	5.70	-0.10		-0.06	0.00			
18	5.40	5.40	0.00		0.04	0.00			
19	5.30	5.60	0.30		0.34	0.11			

TABLE 21

TROXLER (A) VS TROXLER (B)
UNCORRECTED UNCORRECTED

(A) - SAMPLE ORDER TROXLER TO CAMPBELL
(B) - SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.41	6.21	-0.20	-0.03	-0.17	0.03	0.18	0.04	-0.6221
2	6.72	6.65	-0.07		-0.04	0.00			
3	6.57	6.39	-0.18		-0.15	0.02			
4	6.39	6.37	-0.02		0.01	0.00			
5	6.58	6.42	-0.16		-0.13	0.02			
6	6.63	6.59	-0.04		-0.01	0.00			
7	6.23	6.28	0.05		0.08	0.01			
8	6.21	6.40	0.19		0.22	0.05			
9	6.30	6.09	-0.21		-0.18	0.03			
10	5.50	5.34	-0.16		-0.13	0.02			
11	5.66	5.96	0.30		0.33	0.11			
12	5.96	5.98	0.02		0.05	0.00			
13	5.56	5.93	0.37		0.40	0.16			
14	6.13	6.12	-0.01		0.02	0.00			
15	6.33	6.25	-0.08		-0.05	0.00			
16	6.63	6.82	0.19		0.22	0.05			
17	6.44	6.08	-0.36		-0.33	0.11			
18	5.97	5.86	-0.11		-0.08	0.01			
19	6.03	6.01	-0.02		0.01	0.00			

TABLE 22

CAMPBELL (A) VS. CAMPBELL (B)
UNCORRECTED UNCORRECTED

(A) - SAMPLE ORDER TROXLER TO CAMPBELL
(B) - SAMPLE ORDER CAMPBELL TO TROXLER

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.44	6.26	-0.18	-0.11	-0.07	0.01	0.26	0.06	-1.7932
2	6.76	6.40	-0.36		-0.25	0.06			
3	6.49	6.32	-0.17		-0.06	0.00			
4	6.29	6.44	0.15		0.26	0.07			
5	6.54	6.43	-0.11		0.00	0.00			
6	6.40	6.36	-0.04		0.07	0.00			
7	6.06	6.16	0.10		0.21	0.04			
8	6.27	6.19	-0.08		0.03	0.00			
9	6.37	6.10	-0.27		-0.16	0.03			
10	5.53	5.21	-0.32		-0.21	0.04			
11	5.44	5.90	0.46		0.57	0.32			
12	5.81	6.01	0.20		0.31	0.10			
13	5.56	5.68	0.12		0.23	0.05			
14	6.13	5.95	-0.18		-0.07	0.01			
15	6.27	6.26	-0.01		0.10	0.01			
16	6.79	6.86	0.07		0.18	0.03			
17	6.62	5.93	-0.69		-0.58	0.34			
18	6.15	5.79	-0.36		-0.25	0.06			
19	6.15	5.75	-0.40		-0.29	0.08			

TABLE 23

Troxler Nuclear Gauge vs. Campbell Nuclear Gauge
Uncorrected Uncorrected

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	6.41	6.44	0.03	-0.05	0.08	0.01	0.13	0.02	-2.5096
2	6.21	6.26	0.05		0.10	0.01			
3	6.72	6.76	0.04		0.09	0.01			
4	6.65	6.40	-0.25		-0.20	0.04			
5	6.57	6.49	-0.08		-0.03	0.00			
6	6.39	6.32	-0.07		-0.02	0.00			
7	6.39	6.29	-0.10		-0.05	0.00			
8	6.37	6.44	0.07		0.12	0.01			
9	6.58	6.54	-0.04		0.01	0.00			
10	6.42	6.43	0.01		0.06	0.00			
11	6.63	6.40	-0.23		-0.18	0.03			
12	6.59	6.36	-0.23		-0.18	0.03			
13	6.23	6.06	-0.17		-0.12	0.01			
14	6.28	6.13	-0.15		-0.10	0.01			
15	6.21	6.27	0.06		0.11	0.01			
16	6.40	6.19	-0.21		-0.16	0.03			
17	6.30	6.37	0.07		0.12	0.01			
18	6.09	6.10	0.01		0.06	0.00			
19	5.50	5.53	0.03		0.08	0.01			
20	5.34	5.21	-0.13		-0.08	0.01			
21	5.66	5.44	-0.22		-0.17	0.03			
22	5.96	5.90	-0.06		-0.01	0.00			
23	5.96	5.81	-0.15		-0.10	0.01			
24	5.98	6.01	0.03		0.08	0.01			
25	5.56	5.56	0.00		0.05	0.00			
26	5.93	5.68	-0.25		-0.20	0.04			
27	6.13	6.13	0.00		0.05	0.00			
28	6.12	5.95	-0.17		-0.12	0.01			
29	6.33	6.27	-0.06		-0.01	0.00			
30	6.25	6.26	0.01		0.06	0.00			
31	6.63	6.79	0.16		0.21	0.04			
32	6.82	6.86	0.04		0.09	0.01			
33	6.44	6.62	0.18		0.23	0.05			
34	6.08	5.93	-0.15		-0.10	0.01			
35	5.97	6.15	0.18		0.23	0.05			
36	5.86	5.79	-0.07		-0.02	0.00			
37	6.03	6.15	0.12		0.17	0.03			
38	6.01	5.75	-0.26		-0.21	0.04			

TABLE 24

Campbell Nuclear Gauge vs. Known Asphalt Content
Uncorrected Uncorrected

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	5.79	6.00	0.21	0.13	0.08	0.01	0.12	0.03	4.4783
2	5.66	5.80	0.14		0.01	0.00			
3	6.09	6.20	0.11		-0.02	0.00			
4	5.31	5.50	0.19		0.06	0.00			
5	6.19	6.50	0.31		0.18	0.03			
6	5.17	5.00	-0.17		-0.30	0.09			
7	6.98	7.00	0.02		-0.11	0.01			
8	5.57	5.80	0.23		0.10	0.01			
9	5.50	5.50	0.00		-0.13	0.02			
10	6.09	6.30	0.21		0.08	0.01			
11	5.12	5.20	0.08		-0.05	0.00			
12	6.40	6.60	0.20		0.07	0.00			
13	5.16	5.20	0.04		-0.09	0.01			
14	5.70	5.90	0.20		0.07	0.00			
15	6.50	6.80	0.30		0.17	0.03			
16	5.04	5.10	0.06		-0.07	0.01			
17	6.20	6.30	0.10		-0.03	0.00			

TABLE 25

Laboratory Vacuum Extraction vs. Known Asphalt Content
Corrected by TM 311(M)-86 — Uncorrected

NOTE: d=X2-X1; D=ave. d; Sd=std.dev.; SD=Sd/sqrt(N); t=D/SD

N	X1	X2	d	D	(d-D)	(d-D)^2	Sd	SD	t
1	4.93	5.00	0.07	0.16	-0.09	0.01	0.12	0.02	6.5433
2	4.69	5.00	0.31		0.15	0.02			
3	4.87	5.00	0.13		-0.03	0.00			
4	5.53	6.00	0.47		0.31	0.10			
5	5.67	6.00	0.33		0.17	0.03			
6	5.89	6.00	0.11		-0.05	0.00			
7	4.85	5.00	0.15		-0.01	0.00			
8	4.88	5.00	0.12		-0.04	0.00			
9	4.82	5.00	0.18		0.02	0.00			
10	5.80	6.00	0.20		0.04	0.00			
11	5.94	6.00	0.06		-0.10	0.01			
12	5.89	6.00	0.11		-0.05	0.00			
13	5.08	5.00	-0.08		-0.24	0.06			
14	4.76	5.00	0.24		0.08	0.01			
15	4.94	5.00	0.06		-0.10	0.01			
16	5.85	6.00	0.15		-0.01	0.00			
17	5.88	6.00	0.12		-0.04	0.00			
18	5.85	6.00	0.15		-0.01	0.00			
19	4.90	5.00	0.10		-0.06	0.00			
20	4.92	5.00	0.08		-0.08	0.01			
21	4.94	5.00	0.06		-0.10	0.01			
22	5.80	6.00	0.20		0.04	0.00			
23	5.65	6.00	0.35		0.19	0.04			
24	5.92	6.00	0.08		-0.08	0.01			

TABLE 26

Precision of Capmbell AC-2 Nuclear Asphalt Gauge
Based on procedure from ASTM D4125-83.

Test #	Count #	% AC
1	12692	6.12
2	12675	6.11
3	12609	6.05
4	12678	6.11
5	12657	6.09
6	12657	6.09
7	12604	6.05
8	12651	6.09
9	12753	6.18
10	12633	6.07
11	12677	6.11
12	12792	6.21
13	12728	6.15
14	12648	6.09
15	12899	6.30
16	12925	6.32
17	12849	6.26
18	12776	6.19
19	12741	6.17
20	12740	6.16
SUM	254384	116.62
S. D.	91.38	0.08

Precision is standard deviation divided by calibration slope

Precision = 91.38/1171.84 = 0.0831%

Precision acceptability is < 0.15%

TABLE 27

Precision of Capmbell AC-2 Nuclear Asphalt Gauge
Based on procedure from ASTM D4125-83.

Test #	Count #	% AC
1	12595	6.04
2	12704	6.13
3	12622	6.06
4	12621	6.06
5	12972	6.36
6	12824	6.24
7	13072	6.45
8	12761	6.18
9	12834	6.24
10	12734	6.16
11	12736	6.16
12	12889	6.29
13	12639	6.08
14	12710	6.14
15	12791	6.21
16	12677	6.11
17	12773	6.19
18	12746	6.17
19	12803	6.22
20	12774	6.19
SUM	255277	123.68
S. D.	118.23	0.1

Precision is standard deviation divided by calibration slope.

Precision = 118.23/1171.84 = 0.1009%

Precision acceptability is < 0.15%

TABLE 28

CATEGORY (1) SAMPLE ORDER TROXLER TO CAMPBELL

TABLE #	1	2	3	4	5	6
AVERAGE DIFFERENCE	-0.67	-0.66	-0.37	-0.35	-0.26	-0.25
STANDARD DEVIATION	0.26	0.34	0.28	0.33	0.29	0.34
t OBSERVED	-11.154	-8.457	-5.776	-4.646	-4.011	-3.148
t CRITICAL	2.093	2.093	2.093	2.093	2.093	2.093

****

CATEGORY (2) SAMPLE ORDER CAMPBELL TO TROXLER

TABLE #	7	8	9	10	11	12
AVERAGE DIFFERENCE	-0.64	-0.56	-0.36	-0.27	-0.25	-0.16
STANDARD DEVIATION	0.22	0.26	0.20	0.24	0.20	0.25
t OBSERVED	-12.912	-9.252	-7.927	-4.867	-5.423	-2.741
t CRITICAL	2.093	2.093	2.093	2.093	2.093	2.093

****

CATEGORY (3) SAMPLE VALUES ARE AVERAGE OF 1 & 2

TABLE #	13	14	15	16	17	18
AVERAGE DIFFERENCE	-0.65	-0.60	-0.35	-0.30	-0.25	-0.19
STANDARD DEVIATION	0.22	0.28	0.22	0.27	0.22	0.28
t OBSERVED	-12.936	-9.344	-7.074	-4.705	-4.920	-2.923
t CRITICAL	2.093	2.093	2.093	2.093	2.093	2.093

TABLE 29

CATEGORY (4) VACUUM vs. NUCLEAR

TABLE #	19	20	21	22	23
AVERAGE DIFFERENCE	-0.21	-0.04	-0.03	-0.11	-0.05
STANDARD DEVIATION	0.21	0.21	0.18	0.26	0.13
t OBSERVED	-4.359	-0.779	-0.622	-1.793	-2.510
t CRITICAL	2.093	2.093	2.093	2.093	2.023

****

CATEGORY (5) NUCLEAR & VACUUM vs. KNOWN

TABLE #	24	25
AVERAGE DIFFERENCE	-0.13	-0.16
STANDARD DEVIATION	0.12	0.12
t OBSERVED	-4.478	-6.543
t CRITICAL	2.110	2.064

REFERENCES

1. Troxler 3241-B Instruction Manual, Troxler Electronics Laboratories, Inc., 1986, 2nd Edition.

2. Operator's Manual AC-2 Asphalt Content Gauge, CPN Corporation.

3. Effects of Temperature and Moisture Content on Asphalt Content Determination by the Nuclear Method, Clemson University, 1985.

4. Principles of Construction of Hot Mix Asphalt Pavement, The Asphalt Institute, (MS-22), January 1983.

5. Threshold Limit Values and Biological Exposure Indices for 1986-1987, America Conference of Governmental Industrial Hygienists, 1986.

6. Federal Register, Volume 52, Number 153, Monday August 10, 1987.

7. Group Goes After Toxic Chemicals, Statesman-Journal, Tuesday January 26, 1988, Page 1A.

8. Statistical Analysis for Decision Making, Harcourt/Brace/ Jovaovich, 1977, 2nd edition.

APPENDIX A

Procedure for Tests Performed on Field Bituminous Mixture

1. Take standard count on both gauges at the start of each day. Remember that the Troxler gauge requires 10 minutes for the gauge to warm up before taking the standard count.

   Record daily count on Daily Gauge Calibration Sheet. (Figure 3)

2. Obtain a representative sample at the plant. Plant operator will take 4 shovel scoops from the back of the truck to fill the sample container. Immediately return to the laboratory.

3. Place sample on splitting device. Mix sample and quarter into 4 representative samples. This is procedure (OSHD TM 368-85), which is a modification ofAASHTO T-168.

4. Prepare 2 test samples:

   a. Precoat sample pan with non-stick spray.
   b. Fill pans 1/3 way and compress with spoon.
   c. Finish filling pans in 2 more lifts, repeating the same process.
   d. The final weight should equal the base weight plus the weight of the pan.

      eg.:

pan weight	594.3
sample base weight	6843.7
desired weight	7438.0

      Remember, the sample base weight can be $\pm$ 1 g. from this desired weight.

   e. Place board on sample and compress sample with top of pan.

   f. Take sample temperature with probe.

5. Place one sample in each nuclear gauge and perform test analysis by the nuclear gauge method:

   a. Select appropriate calibration curve, which corresponds the bituminous mix design.

   b. Perform four, four-minute counts on each sample. NOTE: The Troxler gauge prompts the user for the temperature each time the sample is tested. Take the previous reading minus 5° F for each succeeding test.
   c. Label the sample put in troxler gauge first as

XXFA. The F symbolizes a sample taken from the field (XX is an integer). This sample will be sent to the field for extraction. (A) designates the sample was tested in the Troxler gauge first.

d. Label the sample put in the Campbell gauge first as XXFB. This sample will be sent to the lab for extraction. (B) designates the sample was tested in the Campbell gauge first.

e. Record results on sheet labeled "Asphalt Content of Bituminous Mixture by Nuclear Method". (Figure 4)

6. After completing the test cycle, place the samples in opposite gauges and repeat the testing.

7. While samples are being tested, prepare 5 pans for moisture content determination:

1 - 1000 g. sample in glass pan for aggregate crew to determine moisture by the microwave oven method. (TM 311(M)-86).

4 - 2000 g. samples to determine moisture by convection oven method.

Two will go to the 230° F oven over night (24 hrs.)
Two will go to the 325° F oven over night (24 hrs.)

8. While still warm, remove samples from pan. Place sample XXFA in two sample boxes, and place sample XXFB in two plastic bags. Give sample XXFA to field personnel for vacuum extraction, and give sample XXFB to laboratory aggregate crew for vacuum extraction.

9. When all testing is completed, record extraction, nuclear gauge, and moisture content results on the summary sheet.

APPENDIX B

Procedure for Tests Performed on Laboratory Fabricated Samples

1. Sample Preparation

   a. Size of sample:

   The size of the sample is the amount of aggregate required to fill the stainless steel pan. This weight will vary depending on the aggregate source, but it will generally be between 6000 and 8000 grams.

   b. Determination of base weight:

   Our mixing equipment is not capable of mixing a 6000 or 8000 gram sample. The capacity is about 2300 grams, so three batches were made. It would be advantageous to mix the sample in it's entirety. The "B" mix with the following proportions was selected for this study:

SIEVE SIZE:	% ACCUMULATED	ACCUMULATED WEIGHT
1/2	11.0	250.8 GMS.
3/8	20.0	456.0 GMS.
1/4	40.0	912.0 GMS.
#4	50.0	1140.0 GMS.
#10	70.0	1596.0 GMS.
#40	89.0	2096.0 GMS.
#200	97.0	2211.6 GMS.
P200	100.0	2280.0 GMS.

One of the batched aggregate samples was placed in the stainless steel sample pan. The material was then leveled to fill in any voids. From the second batched sample, enough material was put in the pan to fill it approximately half full. Again, the material was leveled. With the pan half full, it was lifted one inch above the table top and dropped. This again was to fill in any voids and to make the sample homogeneous. The remainder of the second aggregate sample was placed in the pan and leveled. The third sample was placed in the pan until the material was heaped above the rim. The pan was then lifted about an inch above the table top and dropped. The material was then struck off level with the rim of the pan. The aggregate and the pan were then weighed. Once the pan weight is subtracted, the result is the "base weight", and is the weight that is used on all test samples throughout our study.

c. Calibration samples preparation:

The nuclear asphalt content gauge is calibrated using two samples. One sample is one percent above the design asphalt content and the other is one percent below. The design asphalt content is six percent, so a sample is mixed at five percent and at seven percent. The weights during mixing is closely monitored to track any gains or losses in moisture. Calibration Samples for Nuclear A/C Content Gauge (Figure 5) was designed to record the weights during the mixing. The batched aggregate is oven dried overnight at 325° F. The material is weighed and the desired A/C content calculated using the following formula:

$$\text{Desired Asphalt Content} = \frac{\text{Agg. Wt. X \% Asphalt}}{\text{100 - \% Asphalt}}$$

The samples are mixed and put in the sample pan following the same procedure used for the base weight determination. The weight of the sample to be tested must be equal the base weight. The base weight is obtained by spooning material into the sample pan until base weight was reached. The mix is leveled with a spoon to fill the corners and any voids that might exist. Using a board, the mix is compacted and leveled in the sample pan. This was accomplished by laying the board on top of the sample and by standing on the board. The weight of the sample was again checked.

One important item is to keep the pan and partial sample hot while waiting for additional material to be mixed. This reduced the amount of moisture gained in the sample.

APPENDIX C

FIGURE 3

DAILY CALIBRATION

	CAMPBELL			TROXLER		
DATE	STD.	P	CHI	STD.	P	CHI

FIGURE 4

ASPHALT CONTENT OF BITUMINOUS MIX BY NUCLEAR METHOD

PROJECT: DATE:
ASPHALT BRAND & GRADE: SAMPLE #:
SOURCE # & NAME: A/C %:
MIX TYPE:

BASE WT._____ SAMPLE WT._____

	CAMPBELL	TROXLER
MODEL		
SERIAL NO.		
CALIBRATION INFORMATION:		
CALIBRATION #		
SLOPE		
INTERCEPT		
CORRELATION COEF.		
BACKGROUND COUNT		
(AT TIME OF CALIBRATION)		
TESTING INFORMATION:		
CURRENT STANDARD COUNT		

	CAMPBELL			TROXLER		
TEST #	TEMP	%A/C	COUNT	TEMP	%A/C	COUNT
1						
2						
3						
4						
AVERAGE						

OPERATOR_____

FIGURE 5

CALIBRATION SAMPLES FOR NUCLEAR A/C CONTENT GAUGE

PROJECT NAME: DATE:
ASPHALT BRAND & GRADE: SAMPLE #:
SOURCE NAME & NUMBER: AC %:

MIXING WEIGHTS:

WT. OF MIXING BOWL @ END: _____
WT. OF MIXING BOWL @ START: _____
WT. OF EXCESS MATERIAL IN BOWL: _____

WT. OF SPOON @ END: _____
WT. OF SPOON @ START: _____
WT. OF EXCESS MATERIAL ON SPOON: _____

TOTAL EXCESS MATERIAL: _____

AGGREGATE:
1

WT. OF AGG. & PAN: _____
WT. OF PAN: _____
WT. OF AGG.: _____

DESIRED ASPHALT CONTENT:
(AGG. WT. X % ASPHALT / 100 - % ASPHALT) _____

AGGREGATE:
2

WT. OF AGG. & PAN: _____
WT. OF PAN: _____
WT. OF AGG.: _____

DESIRED ASPHALT CONTENT:
(AGG. WT. X % ASPHALT / 100 - % ASPHALT) _____

AGGREGATE:
3

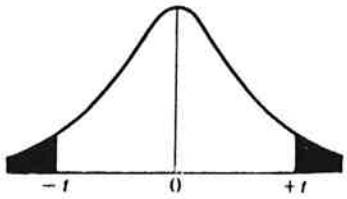
WT. OF AGG. & PAN: _____
WT. OF PAN: _____
WT. OF AGG.: _____

DESIRED ASPHALT CONTENT:
(AGG. WT. X % ASPHALT / 100 - % ASPHALT) _____

TOTAL WT. OF MIXES 1 THRU 3 _____
TOTAL WT. OF MIX IN PAN: _____

APPENDIX D

TABLE A-6
Student's *t*-Distribution



Example For 15 degrees of freedom, the t-value which corresponds to an area of 0.05 in both tails combined is 2131.

Degrees of Freedom	*Area in Both Tails Combined*			
	0.10	0.05	0.02	0.01
1	6.314	12.706	31.821	63.657
2	2.920	4.303	6.965	9.925
3	2.353	3.182	4.541	5.841
4	2.132	2.776	3.747	4.604
5	2.015	2.571	3.365	4.032
6	1.943	2.447	3.143	3.707
7	1.895	2.365	2.998	3.499
8	1.860	2.306	2.896	3.355
9	1.833	2.262	2.821	3.250
10	1.812	2.228	2.764	3.169
11	1.796	2.201	2.718	3.106
12	1.782	2.179	2.681	3.055
13	1.771	2.160	2.650	3.012
14	1.761	2.145	2.624	2.977
15	1.753	2.131	2.602	2.947
16	1.746	2.120	2.583	2.921
17	1.740	2.110	2.567	2.898
18	1.734	2.101	2.552	2.878
19	1.729	2.093	2.539	2.861
20	1.725	2.086	2.528	2.845
21	1.721	2.080	2.518	2.831
22	1.717	2.074	2.508	2.819
23	1.714	2.069	2.500	2.807
24	1.711	2.064	2.492	2.797
25	1.708	2.060	2.485	2.787
26	1.706	2.056	2.479	2.779
27	1.703	2.052	2.473	2.771
28	1.701	2.048	2.467	2.763
29	1.699	2.045	2.462	2.756
30	1.697	2.042	2.457	2.750
40	1.684	2.021	2.423	2.704
60	1.671	2.000	2.390	2.660
120	1.658	1.980	2.358	2.617
Normal Distribution	1.645	1.960	2.326	2.576

Source: Table A-6 is taken from Table III of Fisher and Yates: *Statistical Tables for Biological, Agricultural and Medical Research*, published by Oliver and Boyd Ltd., Edinburgh, and by permission of the authors and publishers.

SUPPLEMENTAL REPORT 6-30-87 (Add. comments, use of 0.4% PBS for MR freeze-thaw)

PRELIMINARY BITUMINOUS MIXTURE DESIGN

Highway Division
Materials Section

Laboratory No. 87 5247
Data Sheet No. AB50001-03
Prefix C10376
Amount Charge $55.00
Date Received 4-29-87
Date Reported 5-22-87

Project— 12TH STREET SE. - 24TH STREET SE (SALEM)
Contractor: Prime— MOSEMAN CONSTRUCTION Mix Type Class— "B" AC
Paving— Contract No.— 10376 Fed. Aid No.— IX-1560 (6)
Engineer: Region— W.G. ANHORN Resident— WILLIAM H. PIETE 8054

AGGREGATE GRADATION: Source— Hilroy #24-2-2 Type— Gravel

Aggregate Size	3/4-1/4		1/4-10		10-0					Combined Dry Sieve	Agg. Grad. Extracted
% Comb.	35		26		39						
1"	100	100								100	100
3/4	95	95								98	99
1/2	68	68								89	88
3/8	37	37	100	100	100	100				78	78
1/4	7.3	8	74	74	98	98				60	61
10	5	5	8.0	10	71.0	72				31	32
40	3	3	2.5	5	28.9	30				12	14
200 (Dry)	0.5		1.8		7.5					3.6	4.3
200 (Wet)		1		3		10					
No. Ave.	PA		PA		PA						

TEST DATA: Asphalt Brand/Grade— Chevron AR4000W 87-4544 Additive— —

Percent Asphalt (total mix)	5.0	5.5	6.0	6.5	7.0
Asphalt Film	Dry-Suff	Suff	Suff	Suff-Thick	Thick
Sp. Gr. @ 1st Comp. (T-246)	2.30	2.32	2.34	2.36	2.38
Percent Voids @ 1st Comp.	8.0	6.4	4.8	3.4	1.8
Stability @ 1st Comp. (T-247)	34	34	35	36	29
Sp. Gr. @ 2nd Comp.	2.36	2.38	2.40	2.42	2.42
Percent Voids @ 2nd Comp.	5.6	4.0	2.4	0.9	0.2
Stability @ 2nd Comp.	44	43	42	37	24
Max. Sp. Gr. (T-209)	2.499	2.479	2.458	2.443	2.424
Index Ret. Str. (T-165) Chevron AR4000W	61%		79%		81%
Index Ret. Str. (T-165)					
Index Ret. Str. (T-165)					

~~RECOMMENDATIONS:~~ Job Mix Formula:

Aggregate Gradation		Asphalt Content:	Sp. Gr @ 100% Comp.	T-209 T/1306	Design Voids 100% Comp.	@ 1 St
1"	100	Wearing course— 6.0	2.40	2.458	2.4	4.8
3/4	99	Base course— 6.0	2.40	2.458	2.4	4.8
1/2	89	Shoulder course— 6.0	2.40	2.458	2.4	4.8
3/8	78	PMBB—				
1/4	60	Asphalt:				
10	32	Brand— Chevron	Mix Placement Temp.— 280°F			
40	14	Grade— AR4000W				
200	4.3	Additive— — 0.4% Pave Bond Special				

Comments: Reports 87-5931 & 87-6148 Indicate PBS required For MR Freeze-Thaws
87-4231 - CA-LAR = 14.4%; NA_2SO_4 = 0.7%; Deg = 19.4%, 0.6"; Friable = 0.5%
87-4232 - FA - ——— ; " = 2.3%; " = 16.0%, 0.6"; " = 0.1%
87-4233 - FA - ——— ; " = 2.3%; " = 16.0%, 0.6"; " = 0.7%

Const. x
FHWA x
Reg. Engr.
Res. Engr. x Wm. Piete
Dist. Engr.
Region Geo x R. West
Files 2x
x Moseman Const.

Engineer of Materials

APPENDIX E

OSHD Test Method 3110-86

Method of Test For

MOISTURE CONTENT OF BITUMINOUS PAVING MIXTURES BY USE OF CONVENTIONAL DRYING OVEN

SCOPE

1.1 This method describes the procedure to be used in the Central Laboratory or field for determining the moisture content of hot mixed bituminous mixtures by use of a conventional drying oven.

1.2 Results from this method are used for the moisture correction factor in determining asphalt content in a bituminous mixture.

APPARATUS

2.1 Balance - A balance sensitive and readable to 0.01 gram. (0.2 gram for OSHD Field Lab Trailers only.)

SAMPLE

3.1 The sample for moisture determination shall be representative of the material both as to gradation and moisture. The sample must be immediately covered to prevent loss of moisture between the time the sample is taken and when it is initially weighed.

3.2 When using a balance sensitive to 0.01 gram, weigh a 300 gram (+/-) representative sample of the asphalt concrete mixture into a tared container and record the weight. Dry the sample to constant weight in an oven controlled to 110 $\pm$ 5 degrees C (230 +/- 9 degrees F) and record the dry weight.

3.3 When using a balance sensitive to 0.2 gram, weigh a 1000 gram representative sample of the asphalt concrete mixture into a tared container and record the weight. Dry to constant weight in an oven controlled to 110 +/- 5 degrees C (230 +/- 9 degrees F) and record the dry weight. This method is to be used by the technician when the equipment and conditions outlined in section 3.2 are not available.

Note: The moisture test sample must be weighed as nearly as practicable to the same time as the sample for extraction is weighed to reduce the error from moisture loss.

CALCULATION

4.1 Initial Weight - Final Weight = Moisture Loss.

$$\frac{\text{Moisture Loss}}{\text{Final Weight}} \times 100 = \% \text{ Moisture Content}$$

APPENDIX G

OSHD Test Method 311M-86

Method of Test for

MOISTURE CONTENT OF NON CUT-BACK BITUMINOUS MIXTURES AND GRADED AGGREGATES IN NON CUT-BACK BITUMINOUS MIXTURES USING MICROWAVE OVENS

SCOPE

1.1 This test method provides a rapid field procedure for determining the moisture content in either non cut-back bituminous mixtures or graded aggregates used in non cut-back bituminous mixtures. Its use is limited to bituminous mixtures consisting of paving grade asphalts and emulsified asphalts.

SUMMARY

2.1 A representative 1000 gram sample of the bituminous mix is heated and cooled in a cyclic fashion in a microwave oven under set conditions to drive off moisture present. After cooling, the sample is weighed to determine the amount of moisture lost. This is continued until a constant weight is achieved or until there is observed less than one gram loss for two consecutive weighings.

APPARATUS

3.1 Microwave oven equipped with a timer, programmable up to 30 minutes, a variable power range to 850 watts or more with a minimum of three power settings. (High, Medium and Defrost), and capable of holding a minimum of two samples of 1000 grams each (minimum of 1.4 cubic feet).

3.2 Balance sensitive and readable to 0.01 gram. (0.2 gram for OSHD Field Lab Trailers only).

3.3 Microwave safe containers of paper, glass or ceramic, each capable of holding a 1500 gram sample. 12 inch x 13 inch x 2 inch (30 cm x 33 cm x 5 cm) containers are recommended.

3.4 Temperature measuring instrument with a 100 - 400 degrees F range and accurate to +/- 10 degrees F.

3.5 Protective gloves.

3.6 Wide mouth sample containers, such as wide mouth quart cans or metal concrete cylinder cans with metal lids which can be sealed with tape to prevent loss of moisture.

3.7 Spatula, spoons, and sample splitter for aggregate etc. 63

3.8 A clear white fluorescent tube, one half x six inches (Westinghouse or GE F4T5)

3.9 Stirring Rod.

SAMPLE

4.1 The sample for moisture determination shall be representative of the material both as to gradation and moisture. The sample must be immediately covered to prevent loss of moisture between the time the sample is taken and when it is initially weighed. Test sample shall weigh not less than the following:

Maximum Designated Particle Size	Minimum Moisture Content Sample
1 inch or less	1000 +/- 100 grams
1 inch plus	2000 +/- 200 grams

PROCEDURE

5.1 Select a power level on the microwave oven which will heat the sample to 250 +/- 20 degrees F in a ten minute period. This will vary with each oven. However, a setting which will provide between 250-400 watts output has been found satisfactory. It is essential that the same techniques and equipment be used throughout a project. Differing heating containers or procedures will affect the end results.

5.2 Obtain approximately 2000 grams of material

5.3 Split the material into two 1000 +/- 100 gram samples. When the maximum particle size is one inch or greater, test both 1000 gram samples separately.

5.4 Determine tare weight of approved paper towel lined container to be used.

Note: Tare weigh the stirring rod that will be used to stir the sample, subsequent weighings will include the stirring rod since some asphalt will adhere to the rod, yielding erroneous results if not included.

5.5 Place sample at a uniform thickness in container and weigh to the nearest 0.01 gram (0.2 gram for OSHD Field Lab Trailers only) to obtain the wet weight of the sample.

5.6 Place container with sample in microwave oven, set timer for ten minutes and heat at the pre-determined setting which results in warming the mix to 250 degrees +/- 20 degrees F.

5.7 After ten minutes, remove container with sample from oven, measure temperature, then stir mixture and allow to cool and expel moisture for ten minutes. Weigh to nearest 0.5 gram and record weight and temperature.

5.8 Place container with sample back in oven, adjust power setting as necessary to maintain temperature as close to desired limits as possible, turn on oven and heat for another ten minute period.

5.9 Repeat steps 5.7 and 5.8 twice (a minimum of 3 drying times) and continue until a constant weight has been obtained. A loss of less than one gram after two consecutive weighings will be considered as a constant weight condition.

CALCULATIONS

6.1 Determine the weight of the sample to the nearest 0.01 gram (0.2 gram for OSHD Field Lab Trailers only) after it has been dried to a constant weight.

Dry Weight = Final weight of sample and container minus weight of container

Wet Weight = Original weight of sample and container minus weight of container

6.2 To determine the moisture contents, the weight of the moisture lost is divided by the weight of the dried material. This number multiplied by 100 will give the percent of moisture contained in the material as follows:

$$\text{Moisture Content (\%)} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

6.3 When testing samples of one inch plus particle size, average the results of the two 1000 gram samples.

6.4 Record test data on Daily Plant Report for Bituminous Mixtures Form 734-3083

PRECAUTIONS

7.1 Follow manufacturers instructions for the care and cleaning of the oven and recommendations regarding materials and utensils for use in microwave ovens.

7.2 Check the microwave oven daily for leakage by passing the small fluorescent tube around the entire outside surface with the oven on. Keep the tube one inch or less from the surface. Any lighting of the tube indicates leakage. The oven should not be used until the leakage is corrected as the microwave radiation may be injurious.

7.3 Do not use metal containers in the oven at any time as this may damage the oven.

7.4 Do not use the glass tray in the bottom of the oven for a sample container.

7.5 Never operate the oven when it is empty or without the glass tray.

7.6 Do not use the microwave oven to heat mixtures containing cut-back asphalts.

DISCUSSION

8.1 The microwave oven is not a drying oven. Some of the moisture driven off the bituminous mix continues to circulate in the oven. This makes it difficult to achieve and hold the 250 +/- 20 degrees F temperature after the initial cycle. The temperature of the sample will tend to drop after the first cycle due to the recirculating moisture. From studies performed at the OSHD Materials Lab the best course is to raise the settings during the ensuing cycles to achieve the 250 +/- 20 degees F temperature.