TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

IDEA *Innovations Deserving Exploratory Analysis Project*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report of Investigation

IDEA PROJECT FINAL REPORT
Contract NCHRP-96-IDO32

IDEA Program
Transportation Research Board
National Research Council

June 1997

TESTING AND TRIAL DEPLOYMENT OF A COST-EFFECTIVE AND REAL-TIME ASPHALT PAVEMENT QUALITY INDICATOR SYSTEM

Prepared by:
Peter Sawchuk
&
Robert Sovik
TransTech Systems, Inc.
Latham, New York

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This NCHRP-IDEA investigation was completed as part of the National Cooperative Highway Research Program (NCHRP). The NCHRP-IDEA program is one of the four IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in highway and intermodal surface transportation systems. The other three IDEA program areas are Transit-IDEA, which focuses on products and results for transit practice, in support of the Transit Cooperative Research Program (TCRP), Safety-IDEA, which focuses on motor carrier safety practice, in support of the Federal Motor Carrier Safety Administration and Federal Railroad Administration, and High Speed Rail-IDEA (HSR), which focuses on products and results for high speed rail practice, in support of the Federal Railroad Administration. The four IDEA program areas are integrated to promote the development and testing of nontraditional and innovative concepts, methods, and technologies for surface transportation systems.

For information on the IDEA Program contact IDEA Program, Transportation Research Board, 500 5th Street, N.W., Washington, D.C. 20001 (phone: 202/334-1461, fax: 202/334-3471, http://www.nationalacademies.org/trb/idea)

TABLE OF CONTENTS

SUMMARY

Density of the hot mix asphalt is the most important construction variable in the durability of asphalt pavement surfaces. The current methods of measuring asphalt pavement density today have their limitations. Destructive core samples and laboratory measurement are time consuming and costly. Useful information does not reach the paving crew in time to make any corrections to the paving process. The alternative, nuclear instruments require strict licensing and usage procedures, take several minutes to get data, and have limitations in their accuracy, particularly for thin layers.

The Pavement Quality Indicator developed in this project has been demonstrated to be a viable product for making real time measurements of asphalt pavement density in a non-destructive, non-nuclear format. This product is superior to the nuclear measurement instruments currently used for non-destructive asphalt density measurements today. This electronic sensing instrument is light weight and very easy to use. No licensing processes are required. Virtually any member of the paving crew or department of transportation can easily operate the Pavement Quality Indicator with little training. Pavement readings are instantaneous and data can be electronically transferred to a computer for processing. The accuracy and repeatability of the Product Quality Indicator's density measurements exceeds that of a nuclear instrument.

The market potential for this product as a portable asphalt density measurement instrument is estimated to be over $100 million. Survey work indicates that the demand for this type of product is very high. Virtually all participants interviewed in the survey including contractors, state department of transportation officials, Federal Highway Administration officials, and testing services expressed high interest levels in the product and in obtaining one for use. The ability of the Pavement Quality Indicator to instantaneously read asphalt pavement density creates a cost effective opportunity to dramatically increase the number of density readings taken on the highway and provide real time feedback to the paving crew for timely corrective action.

The next phase will be to verify and debug the prototype developed with an intense beta type field test with selected high profile users in actual field usage. This process will help assure that the product that is initially introduced into the market place is of proven quality and performance.

IDEA PRODUCT

It has been generally accepted by pavement engineers that the density of hot mix asphalt (HMA) is the most important construction variable in the long-term durability of paved surfaces. The product idea being investigated in this project is a pavement quality indicator that can be used to make real time, in-situ measurements of pavement density. The device is intended to provide density measurements based on non-intrusive non-destructive, non-radioactive detection techniques suitable for static and in-motion measurements.

THE PROJECT

1. Design and develop prototype hardware units for achieving real-time assessment of asphalt quality. Assemble three prototype systems and conduct shake-down trial experimentation of the system for determining pavement density of asphalt in real time.
2. Verify the operation of the prototypes in the laboratory and on asphalt.
3. Perform full scale on-road tests to establish the efficacy of the asphalt pavement quality indicator system were conducted. Assess operational feasibility of the pavement quality indicator under highway operational conditions.
4. Develop design revisions (if any are required) based on test results, for commercialization of the system.
5. Discuss implementation plans and identify potential strategies for deployment and marketing of the system to highway agencies and pavement contractors.

RESULTS

PROTOTYPES

A design utilizing an electronic capacitance based sensor system was finalized and three prototype units were assembled (see Attachment #1).

LABORATORY VERIFICATION

The units were given a laboratory and a field shakedown trial to verify initial operation, accuracy, and repeatability. An innovative technique was developed for producing simulated asphalt samples with highly controlled density that could be varied easily over a range of density from 110 pounds per cubic foot to 150 pound per cubic foot. The technique involved the use of multiple plate glass sheets stacked with intervals of air voids. It proved to be quite precise and extremely cost effective for laboratory work. The density curve generated as a result of the laboratory work is shown in Attachment #2.

Certain modifications to the design were necessary as a result of this work including fine tuning of the electrical circuit.

FIELD TESTING

Field testing was done according to an established plan in Attachment #3. Attachment #4. shows the field testing on the fourth test site, US50 outside of Carson City , Nevada. Testing was conducted at 6 sites. A total of 180 core samples were taken, 360 nuclear gauge readings were taken, and 1080 Pavement Quality Indicator readings taken. The locations were as follows:

TABLE 1. Location of Core Sample Readings

Site	Location	Core Samples
Pitsfield Airport	Pitsfield, MA	9
Belmont Avenue	Schenectady, NY	9
Fuller Road	Albany, NY	10
US 50	Carson City, NV	40
I-74	Veedersburg, IN	40
Purdue University		72
	Total	**180**

Fewer test locations were utilized and more data points taken at each site due to weather and the complex logistics involved with going to each site. Operational safety and appropriate pavement availability were key factors requiring this decision. Each test was a learning process. Problems on the site of the first test with the asphalt mix temperature, an unhappy contractor, and incorrect core locations resulted in unusable data, but important, experience that helped with the subsequent tests.

The second test at Belmont Avenue in Schenectady, NY provided good operating results, showing that the PQI unit could function as expected in an actual paving environment (see Attachment #5). However, accuracy levels were below expectations. Further fine tuning was done to the PQI probe and circuitry. Due to the schedule of the job and the available traffic control area, only nine core samples and associated nuclear and PQI readings were taken.

The third test was conducted at Fuller Road in Albany, New York. As with the Belmont Avenue test, less data was collected than planned due to conditions on the job site that day. Attachment #6 shows the repeatability of the PQI instrument. Further fine tuning was done to the instrument as a result of this test.

The fourth test was conducted on Route 50 east of Carson City, Nevada. This location was selected because of the higher metallic content in the aggregate and as a significantly different geographic location (see Attachment #4). More data was collected at this site … 40 cores due to the favorable conditions, primarily good traffic control that enabled timely access to the appropriate asphalt sections. This data provided a good road profile (see Attachment #7). The PQI instrument measures to a controlled depth of 2 ½". Core samples were cut to 2 ½" for the density measurements to achieve a more accurate density reading for comparison to the PQI data. To increase the accuracy of the core density measurement, core samples were accurately measured and weighed and density then determined. Density was also taken by the standard SSD method and a modified dry method using shrink wrap around the cores.

The fifth test was taken at I-74 near Veedersburg, Indiana on a section of recently paved highway. Because of the traffic control situation, 40 core samples were able to be taken. Work was done with the assistance of Tom White of Purdue University Civil Engineering Department. This test produced the best data (see Attachment #8) With an acceptable accuracy limit of +/- 2 lbs/cu ft., 58% of the PQI readings fall within the acceptable range. Only 3% of the nuclear gauge readings fall within the acceptable range. At +/-

2%, 66% of the PQI readings and 3% of the nuclear gauge readings are within the acceptable range. Measurement at the pavement joint is a problem for both the nuclear gauge and the PQI instrument...if this data is removed from the analysis, 84% of the PQI readings and 6% of the nuclear gauge readings fall within the +/- 2% acceptable range. A total of 90.6% of the PQI non joint data points fall within the range of +/- 2.9lbs/cu ft. (see Attachment #9)

Further testing was conducted at Purdue University Civil Engineering Department on a variety of asphalt sheets of varying density and aggregates for testing calibration techniques and additional accuracy testing. The asphalt slabs turned out not to be uniform enough in density for all of the desired calibration work. However, the PQI units were accurate enough to identify these inconsistencies in the density which was good.

At all six test sites, PQI repeatability was excellent. The speed of each PQI reading was 5 seconds. The Indiana DOT nuclear gauge operator at the I-74 Indiana test site commented on how quickly the PQI instrument was able to generate data compared to the nuclear gauge. Moisture conditions had no noticeable effect on the PQI instrument during any of the testing. Ambient temperatures ranged from 30°F to 110° F at the various test sites with no noticeable impact on the PQI instrument. Laboratory and field data indicated that the PQI instrument was measuring to a 2 ½" depth. There were no failures in operation of the PQI during the six field test and the unit was very easy to use.

DESIGN REVISIONS

A new sensor and improved circuit design were completed. To date, testing of this design has been limited, but the results are promising. This improved design will increase the accuracy of the instrument on uneven surfaces such as across joint sections and where small stones are on the pavement surface. This design also has the potential of being lower in cost to manufacture.

MARKET RESEARCH

Market research data was collected on competitive nuclear gauges. Equipment prices range from $5,000 to $8000 (see Attachment #10). Data was also collected on the cost of licensing and maintaining this equipment. The average cost of these additional requirements is approximately $1,000 per year per gauge (see Attachment #11). A survey was conducted to determine the number of nuclear gauges in use for asphalt paving density in the United States. Over 40 formal and informal interviews took place with contractors, state department of transportation officials, federal highway officials, and Laboratory services. Virtually all input received was very positive.

Phase II of the project was completed 30 days ahead of schedule and below the established budget. Phase I of the project was completed on time and below the established budget.

A panel of highway and asphalt pavement practitioners consisting of members from the US Army Corps of Engineers Waterways Experiment Station Pavement Technology Center, Federal Highway Administration Region #1, US Army Corps of Engineers Cold Regions Research & Engineering Laboratory, New York State Department of Transportation, and the Federal Aviation Administration participated in Phase 2. They reviewed and provided input to the test plan as well as reviewing the results of the field testing. The panel had been a valuable asset in providing important input and guidance to the project.

CONCLUSIONS

PRODUCT VIABILITY

We have demonstrated a viable product that can make real time, in-situ measurements of asphalt pavement density in a non-destructive, non radioactive format. This product in its current form is superior to the nuclear measurement instruments currently used for non-destructive asphalt density measurements today. The current prototype product is very easy to use. It weighs less than 10 pounds compared to 29 pounds for a nuclear instrument and is smaller in size. The unit can be used with the operator in a standing position, something that can not be done with a nuclear instrument and is an important factor for increasing productivity by reducing operator fatigue. No licensing processes are required. Virtually any member of the paving crew or department of transportation can easily operate the Pavement Quality Indicator with little training. Pavement density readings take less than 5 seconds to obtain compared to 1 - 2 minutes per reading for nuclear instruments. Data can be electronically collected and transferred for analysis at chosen intervals by computer. The depth of measurement taken by the Pavement Quality Indicator is precise and can be varied to match the depth of the asphalt being placed on the highway. This capability includes precise measurement of thin asphalt layers. Nuclear instruments are not precise in their depth measurement. Demonstrated accuracy is currently better than the nuclear instruments. Repeatability of the Pavement Quality Indicator is excellent in all directions. The current design of this product is cost competitive with the nuclear instruments and as with many electrical designs, has the potential of being lower in cost with future designs. The current Pavement Quality Indicator design can replace existing nuclear density measurement instruments in use today.

MARKET POTENTIAL

The market potential for this product as a portable asphalt density measurement instrument is estimated to be $100 million. Survey work indicated that the demand for this type of product is very high. The Chief Research Engineer in Mississippi stated, " I know of several contractors that would kill to be the first to use the Product Quality Indicator". The state of California (CALTRANS) expressed a strong desire to use the product for thin layer density measurements. A large Indiana contractor who does warranty work and Superpave projects, indicated a very strong desire to use the product. A large contractor in Puerto Rico related a strong need for the product and a desire to use it. Virtually all participants interviewed in the survey including contractors, state department of transportation officials, Federal Highway Administration officials, and testing services are very interested in the product and in obtaining one for use. The ability of the Pavement Quality Indicator to instantaneously read asphalt pavement density creates a cost effective opportunity to dramatically increase the number of density readings taken on the highway and provide real time feedback to the paving crew for instantaneous corrective action. It appears that this measurement technique could replace the current core sample and laboratory analysis used to determine asphalt densities today.

STRATEGIES FOR INTRODUCTION

The strategy for introduction of this product to the market will focus on the Pavement Quality Indicator as a process tool for the contractor to provide real time feedback for improved asphalt lay down. All indications are that the demand for this type of product is very high. This approach will have an immediate impact on the quality of asphalt highways while accumulating an extensive history of performance that can be used to enter other market segments. A secondary strategy will focus on thin layer measurement of asphalt density. Evidence indicates that the nuclear instruments have significant shortcomings in measuring thin layers. The ability of the Pavement Quality Indicator to measure a precise depth will give a higher level of accuracy for thinner depths. Several probes that measure thin layers have already been tested, but further design work focused on thin measurements will result in an even more accurate instrument for these measurements. Additional product development will center on multiple probe configurations for highway density profiling in a dynamic environment and the addition of GPS capability for geographic location.

CHALLENGES

UNEVEN SURFACES

Uneven surfaces can negatively impact the accuracy of the Pavement Quality Indicator. This is the same for the nuclear instruments. Small stones, the asphalt mat joint seam, and the crown at the asphalt mat joint contribute to this problem. It is a situation that nuclear instruments have been living with for years. A revision to the Pavement Quality Indicator design has been completed and partially tested that will accommodate unevenness in the asphalt mat when taking density readings. Further verification of this design improvement is required before it can be fully utilized. This work is planned for Phase 3.

ASPHALT SAMPLES IN THE HIGH & LOW DENSITY RANGES

Most of the field testing work was done on pavements in the standard pavement density ranges of 125 to 145 pounds per cubic foot. Although laboratory testing indicated similar performance at the very high and very low density ranges, little data was collected in these areas because pavement of those densities was not available. Further field data must be collected for these density ranges in Phase 3. A method to obtain this data has been devised.

NEXT PHASE

PROJECT SUMMARY

Phase I and Phase II of the Advanced Pavement Quality Indicator Project have demonstrated the technical and functional feasibility of the asphalt pavement density measuring device. Field testing of prototype units has shown a response time and repeatability unachievable by any of the currently available products and with accuracy comparable to those products. Our market research data indicates a substantial potential market for this product of at least $75 million to $100 million. Virtually every contractor, Federal Highway, and State Department of Transportation official interviewed as part of the market study, was very enthusiastic about the product and its potential applications. Many eagerly volunteered to test the first products. One state DOT department head remarked "there are contractors in this state who would kill to be the first to use this product." This came from one of the most conservative states.

If this product can eventually replace the costly and time consuming core sample process of measurement used today, the market potential will be at least two to three times what has been estimated plus make a very significant contribution to improving the quality of our roadways while reducing costs.

This improved product will be cost competitive with current products and has the potential to be lower in cost, providing much better performance at a comparable or lower price.

Phase III of this project has a scope intended to verify and debug the prototype design through an intense "beta" type field test by selected high profile users in actual field usage. This process will help assure that the product that is initially introduced into the market place is of proven quality and performance. The use of this type of product verification process allows for the introduction of larger numbers of product at the initial launch due to reduced concerns of recalls or reworks that are often seen in newly released products. The cost of Phase III will quickly be recovered with the increased sales in the first two years. Phase III will also address development of a final commercial design, required operator procedures and instructions, as well as establishing a manufacturing process to properly support the new product requirements.

COST

The total cost of this phase of the project is $264,244.

BENEFITS

An advanced, real time Pavement Quality Indicator will:

- Extend pavement life by enabling higher quality construction
- Greatly reduce response time for density readings
- Significantly reduce the cost per measurement of density measurements
- Improve the productivity of paving operations
- Reduce safety hazards, including nuclear material on job sites
- Reduces energy consumption
- Reduces VOC emissions

This Phase III - Pre-commercialization will accelerate the introduction and sales growth of the Pavement Quality Indicator and:

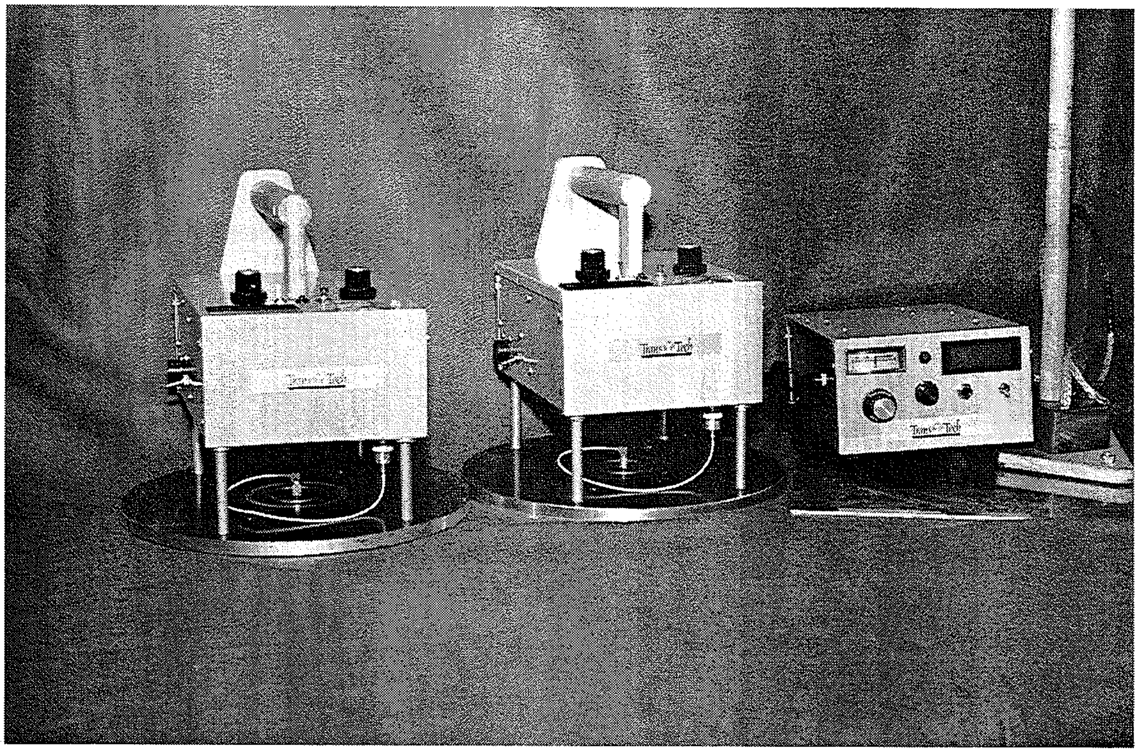
- Provide a quicker return on the funding agencies' investment
- Generate more jobs at TransTech more quickly

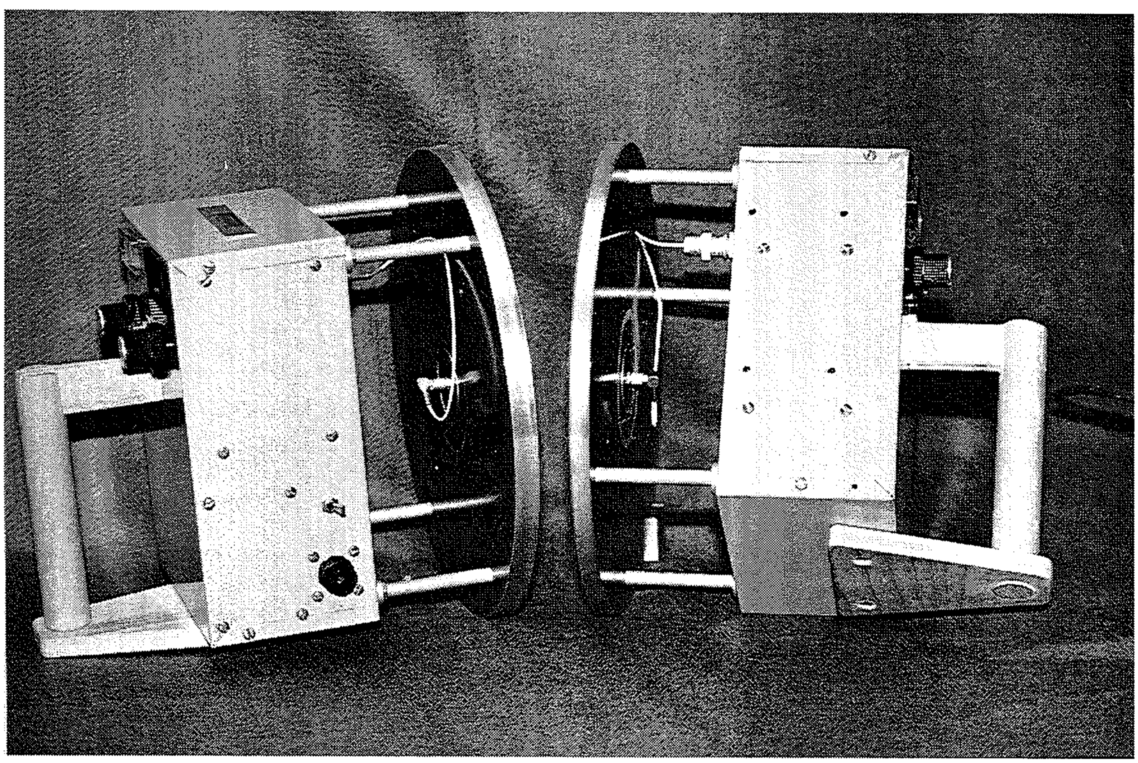
ATTACHMENTS

1. Photographs of PQI Prototypes
2. Density Curve
3. Test Plan
4. Pictures of Nevada Field Test
5. Belmont Avenue Test Graph
6. Fuller Road Test Graph
7. Nevada Test Graph
8. Indiana Test Graph
9. Test Data Accuracy Analysis
10. Competitive Nuclear Gauges and Pricing
11. Nuclear Gauge Maintenance Costs

Attachment #1

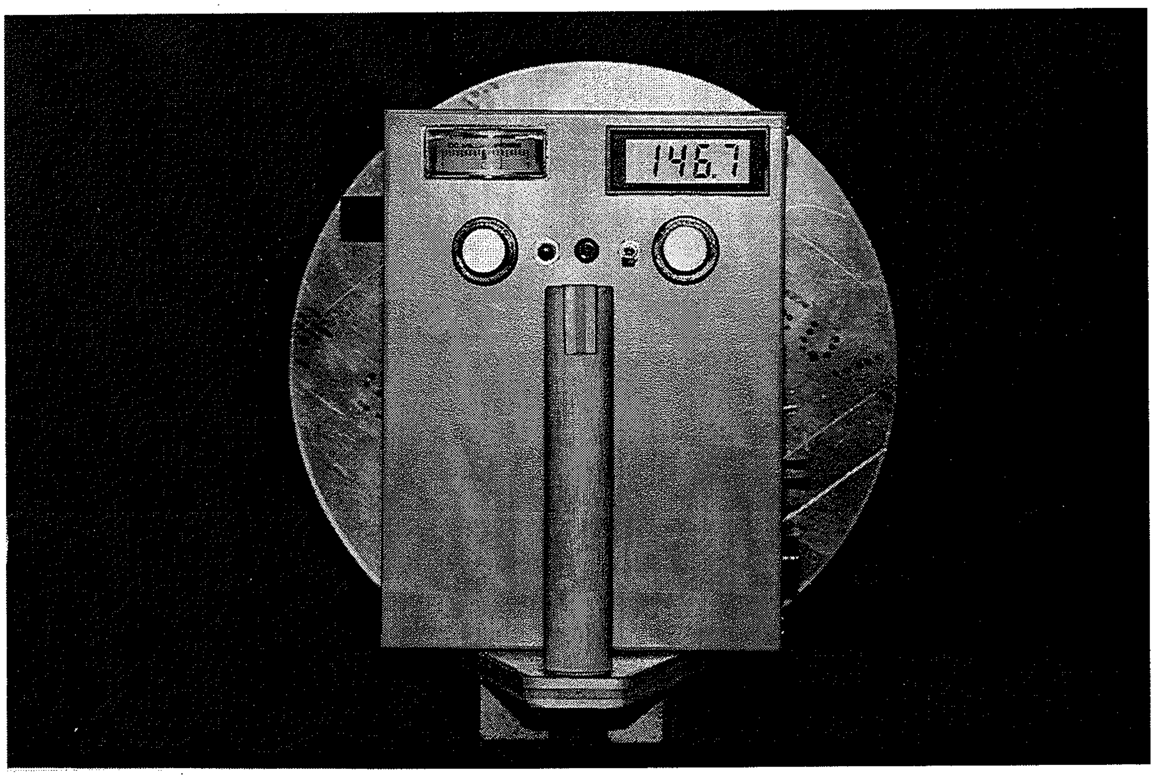
NCHRP - IDEA Project 32

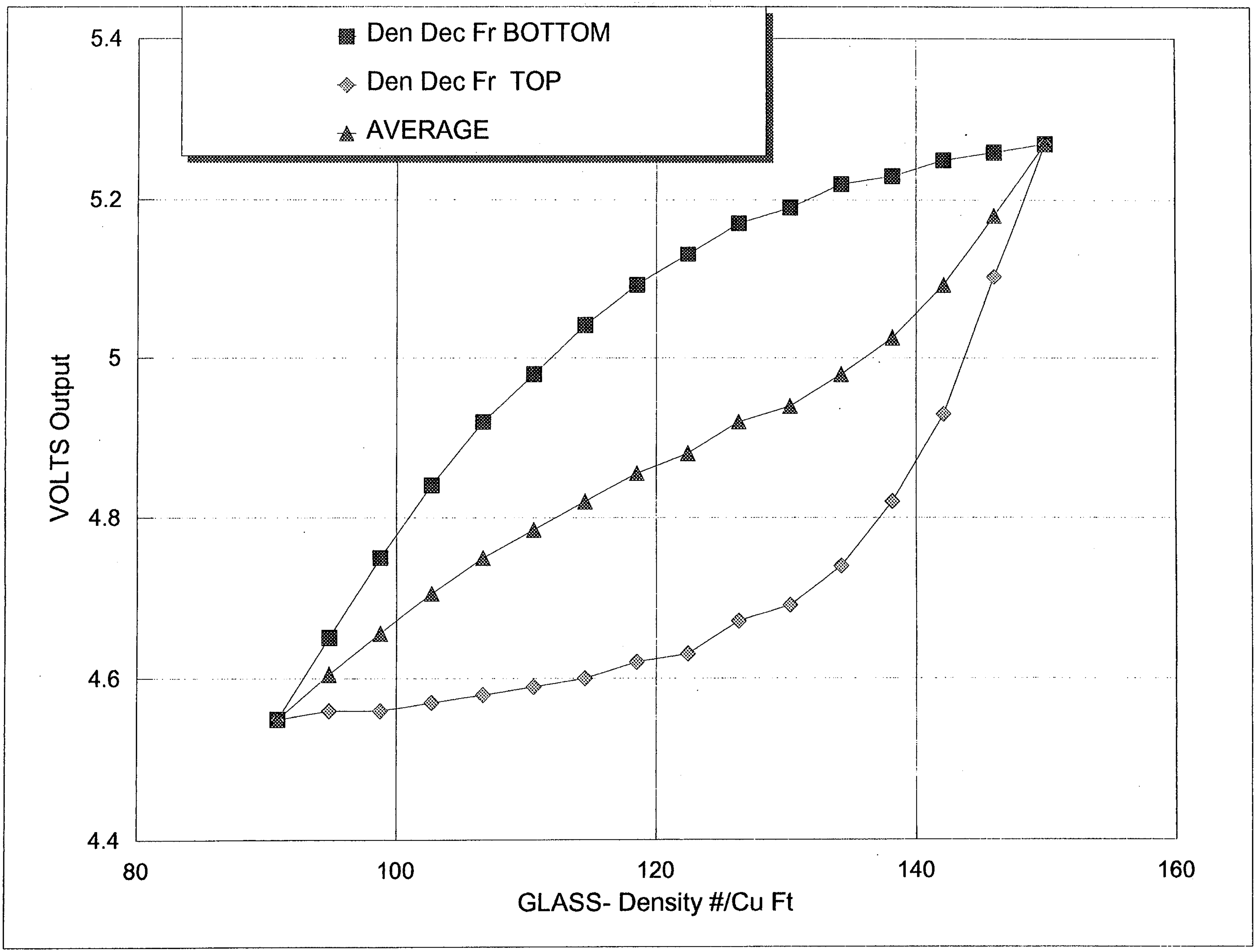




Attachment #1

NCHRP - IDEA Project 32





Attachment #2

Attachment #3

APQI
Field Test Plan
September1996

Purpose

To evaluate functionality, durability, and ease of use of the Pavement Quality Indicator prototype in typical field applications.

Functionality

is comprised of the following areas:

- **Accuracy** - How accurate is the device compared to established equipment? The basis for comparison is 1) core sample data 2) nuclear gauge data.
- **Repeatability** - Will the device provide consistent repetition in providing the same output reading for a known input?
- **Speed of Reading** - How quickly can data be obtained? Laboratory time readings will be verified in the field.
- **Moisture Sensitivity** - The sensing device is affected to varying degrees by moisture. In this application, to what extent will water on the surface of the asphalt as well as in the asphalt affect the accuracy and repeatability of the device?
- **Temperature Sensitivity** - The capacitance sensing devices can be affected by the high end range of ambient temperatures experienced in the field. The design of the electronics is intended to compensate for the affects of temperature changes, with a range of 50°F to 150°F. Verification of this temperature compensation feature will be done during the testing.
- **Depth Penetration** - The sensor probe is designed to sense or read a specific depth associated with the thickness of the asphalt layer to be measured. Different sensor probes are likely to be required for differing depths. Verification of the actual depth penetration will be done in the field testing.
- **Depth profiling** - The ability of the sensor to read variations in density within the layer of asphalt pavement will be conducted in the laboratory and verified in the field.

Durability

Consists of continuous function while in field operation with only normal intermittent maintenance. required. A range of normal field conditions must be accommodated.

Ease of Use

Consists of empirical observations as to how easy the device is to use compared to the established equipment and procedures used in the same function today (core samples and nuclear gauges).

Objectives

- Determine the accuracy of the PQI prototype
- Measure the repeatability of the of the PQI prototype
- Evaluate the speed of PQI data readings
- Evaluate the moisture sensitivity of the prototype
- Evaluate the temperature sensitivity of the prototype
- Evaluate the depth penetration capability of the prototype sensor probe
- Evaluate the depth profiling capability of the prototype
- Evaluate the durability of the prototype
- Evaluate the ease of use of the prototype

Procedure

Accuracy - will be determined by measuring identical pavement sections with the PQI prototype, Nuclear gauge and core samples. The logistics of taking core samples will be the limiting factor on how many cores can be taken at a single site.

Repeatability - will be measured by repeated measurements of the prototype sensor probe on an identical section of asphalt.

Speed of Reading - will be measured for 25 readings and compared to laboratory results already developed. Nuclear gauge field measurement times will also be taken and compared with the prototype times

Moisture - operation under the normal field conditions should encounter a variety of surface water through rain and rolling. Observations of prototype performance will be documented during these conditions. If surface water conditions does not occur naturally, surface water will be introduced at certain intervals in the testing.

Temperature - ambient and mat temperature will be recorded during the testing. Observations will be made with regard to temperature sensitive during the testing and documented for evaluation with the accuracy data.

Depth penetration - of the probe with respect to the mat thickness will be observed and documented for later correlation with the core samples and prior laboratory testing.

Depth profiling - where possible, testing will be done on known multiple layers of asphalt.

Test Site

Each test site will be will be divided into 5 transverse data collection locations approximately 1,000 ft. apart. Data collection readings are taken in the following order for each transverse location:

1) **Base mat** prior to application of the final mat to be measured in item 2.- final mat (where possible)

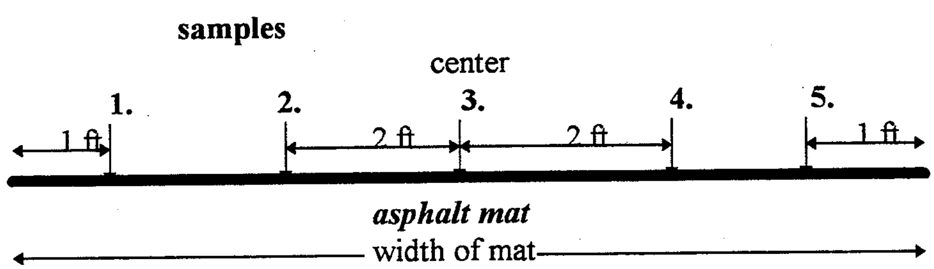
1 PQI and 1 Nuclear gauge measurement at 5 locations

- 1ft. in from each edge of the mat (2 measurements)
- center of the mat
- 2 ft. either side of the center of the mat (wheel rut zone...2 measurements)

2) **Final mat**

1 PQI, 1 Nuclear gauge, and 1 core sample measurement at 5 locations

- 1ft. in from each edge of the mat (2 measurements)
- center of the mat
- 2 ft. either side of the center of the mat (wheel rut zone...2 measurements)



A total of **25 data collection points** will be used for the test.

Ambient temperature and mat temperature at the time of test will be recorded along with any apparent surface moisture. The thickness of the asphalt mat being placed down will be measured and recorded along with the mix specifications and theoretical densities. Speed of measurement, ease of use and any equipment failures will be documented at the test.

A PQI repeatability test will be conducted at two of the 5 transverse data collection locations consisting of 10 repetitions of the 5 established data sample locations on the transverse location. Repetitions will start at location 1. and proceed through to location 5. and then repeat 10 times.

Frequency and Location

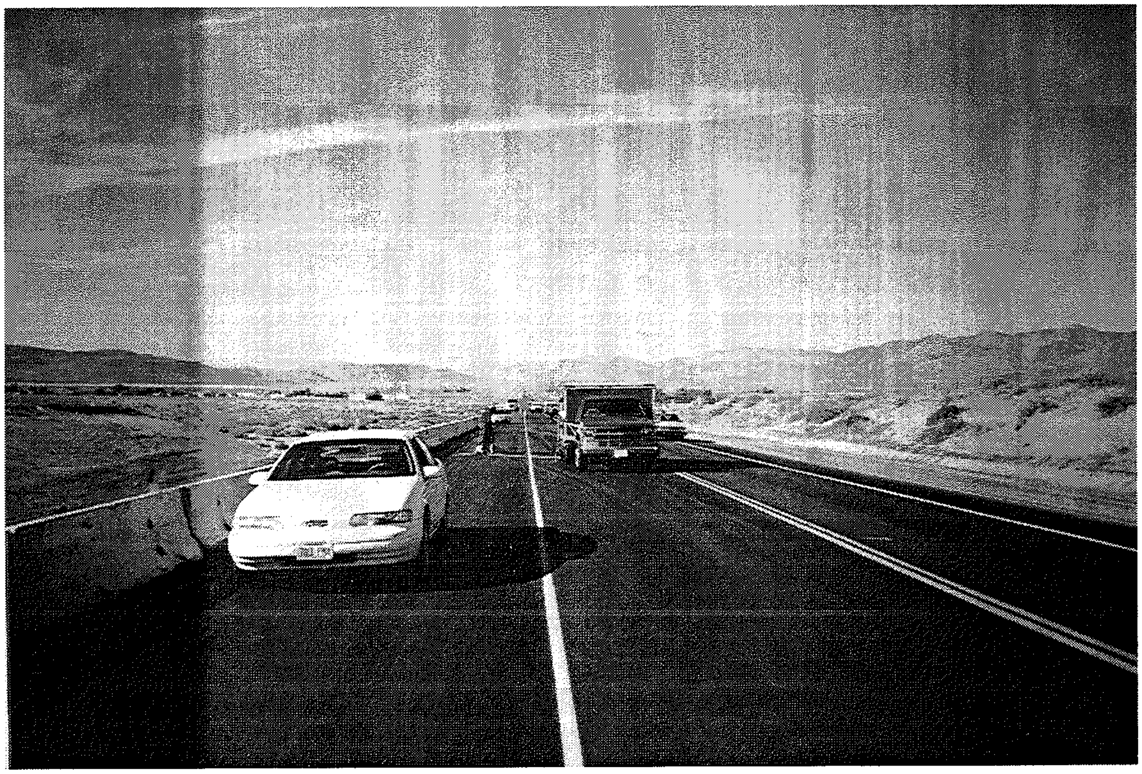
A total of 8 test sites will be completed, providing a total of **200 comparative data points**. The 8 tests will be taken at the following locations:

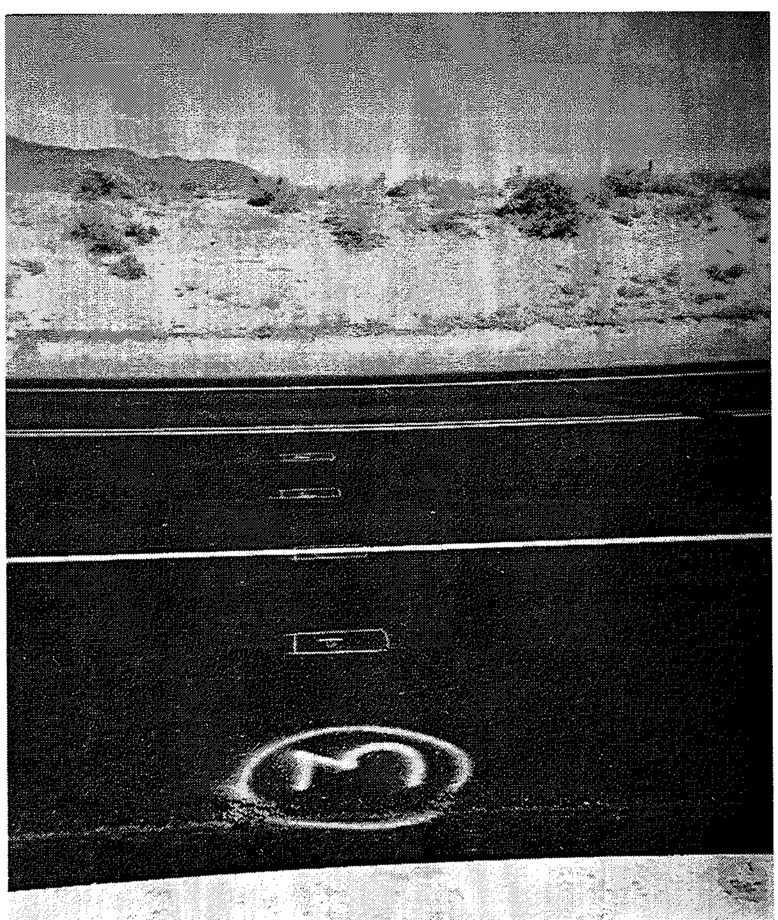
- 4 locations in New York State
- 2 locations is the Midwest
- 2 Locations in Mississippi

**Late season weather conditions may require a change in the plan.

Attachment #4

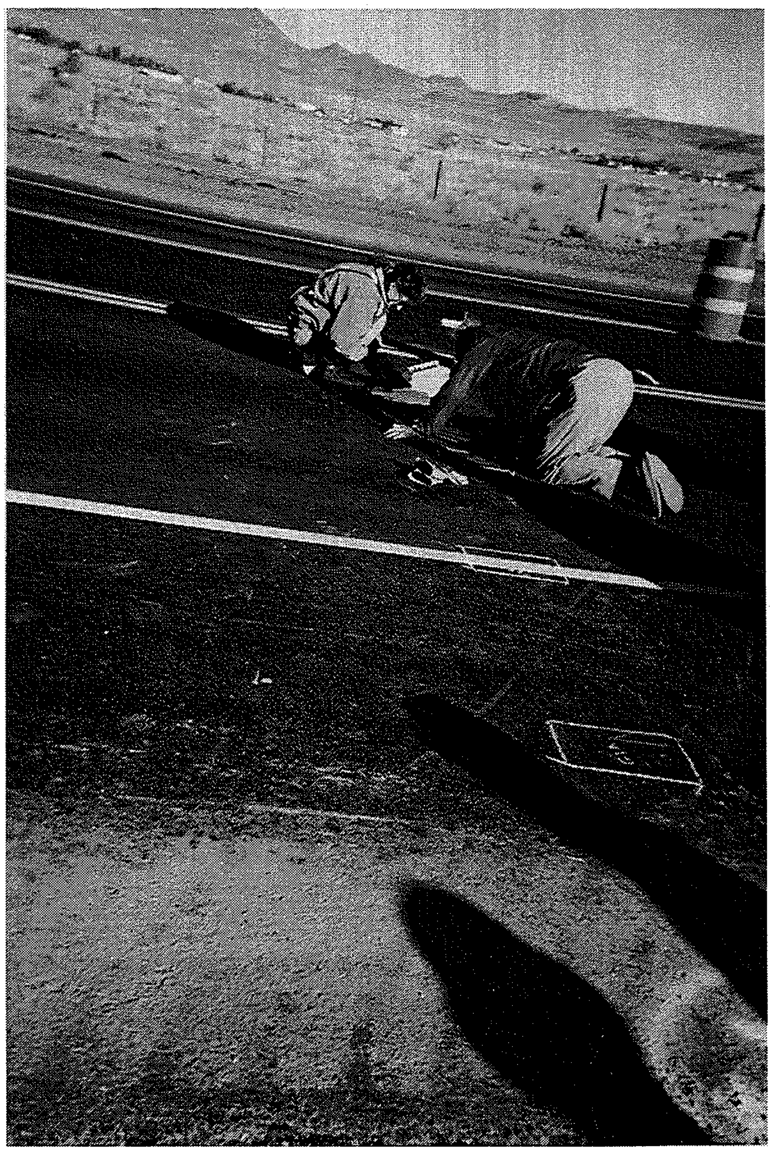
Field Testing
US 50 East of Carson City, Nevada





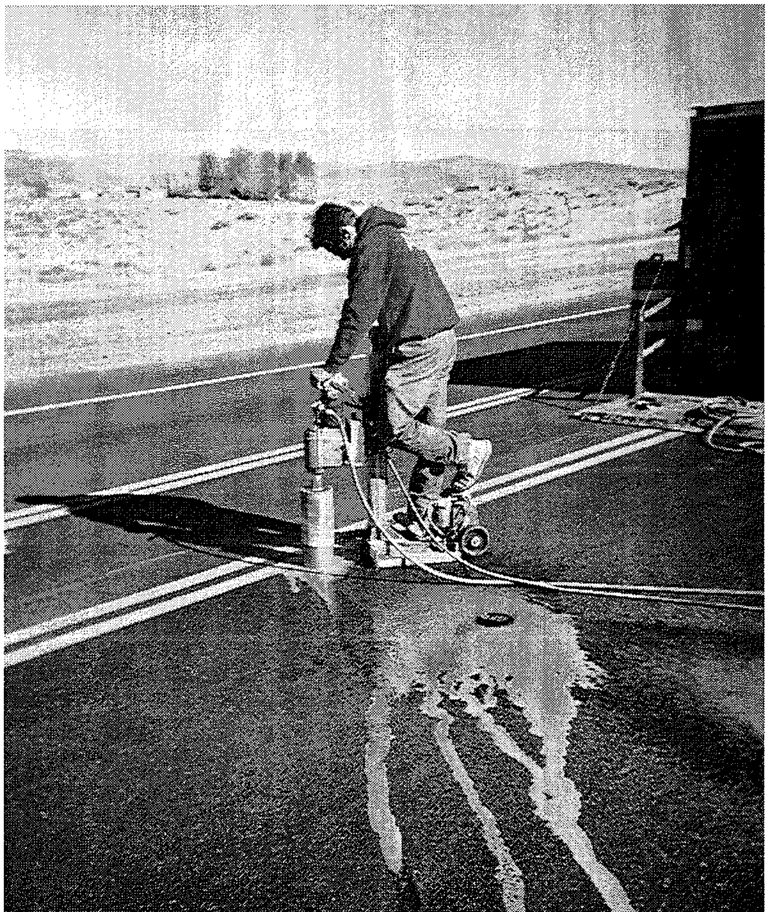
Attachment #4

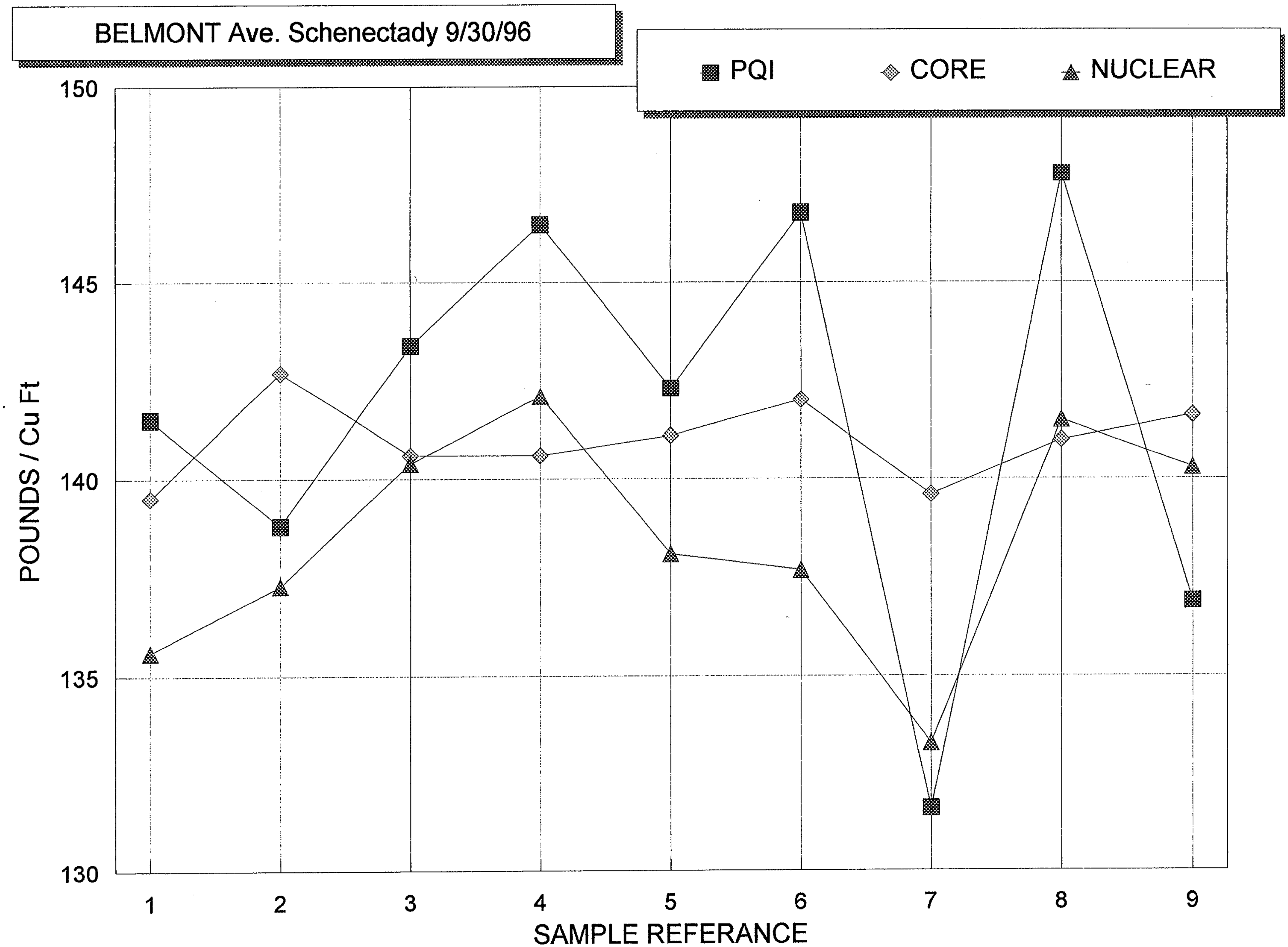
Field Testing
US 50 East of Carson City, Nevada



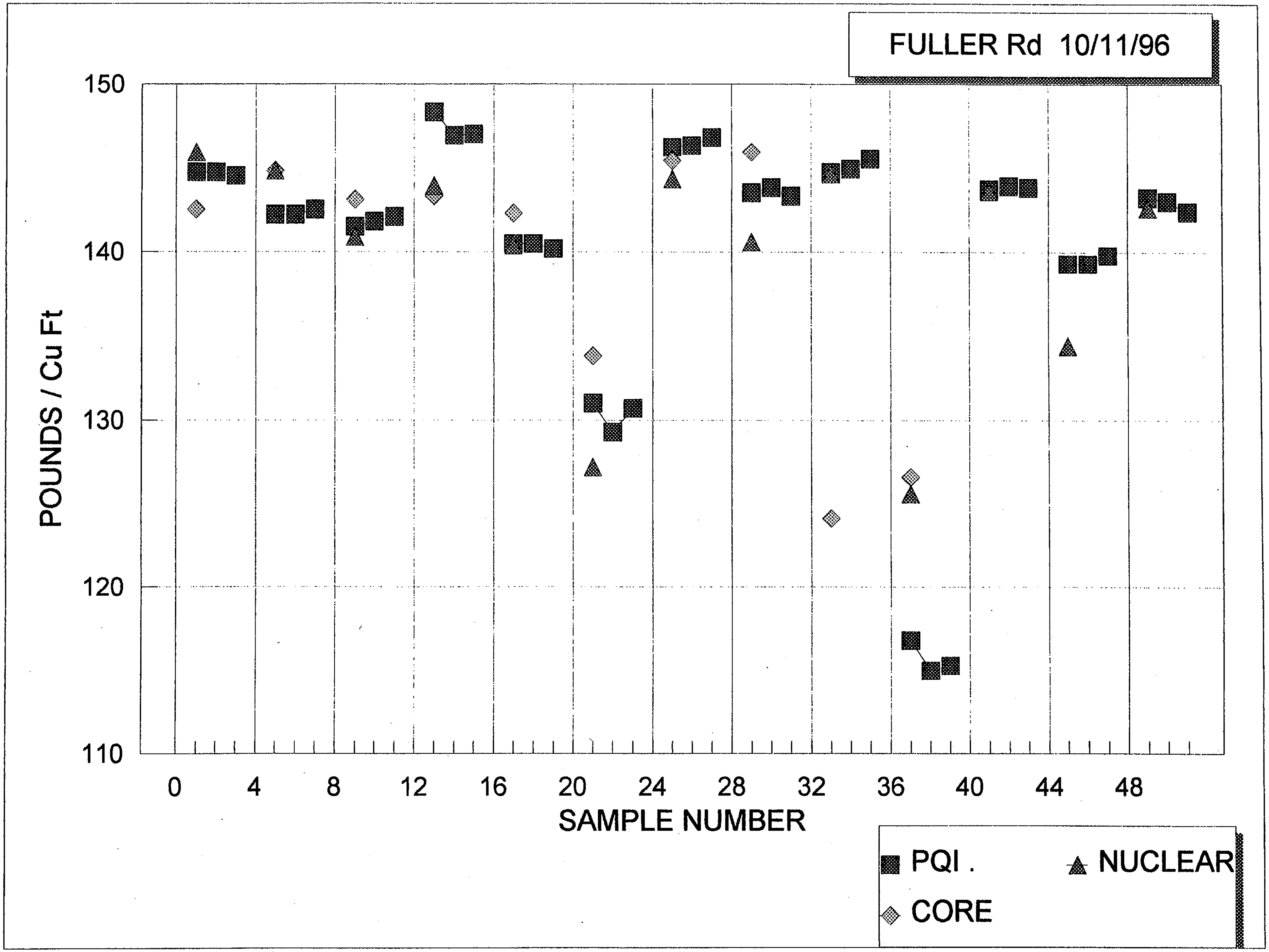
<u>**Attachment #4**</u>

Field Testing
US 50 East of Carson City, Nevada

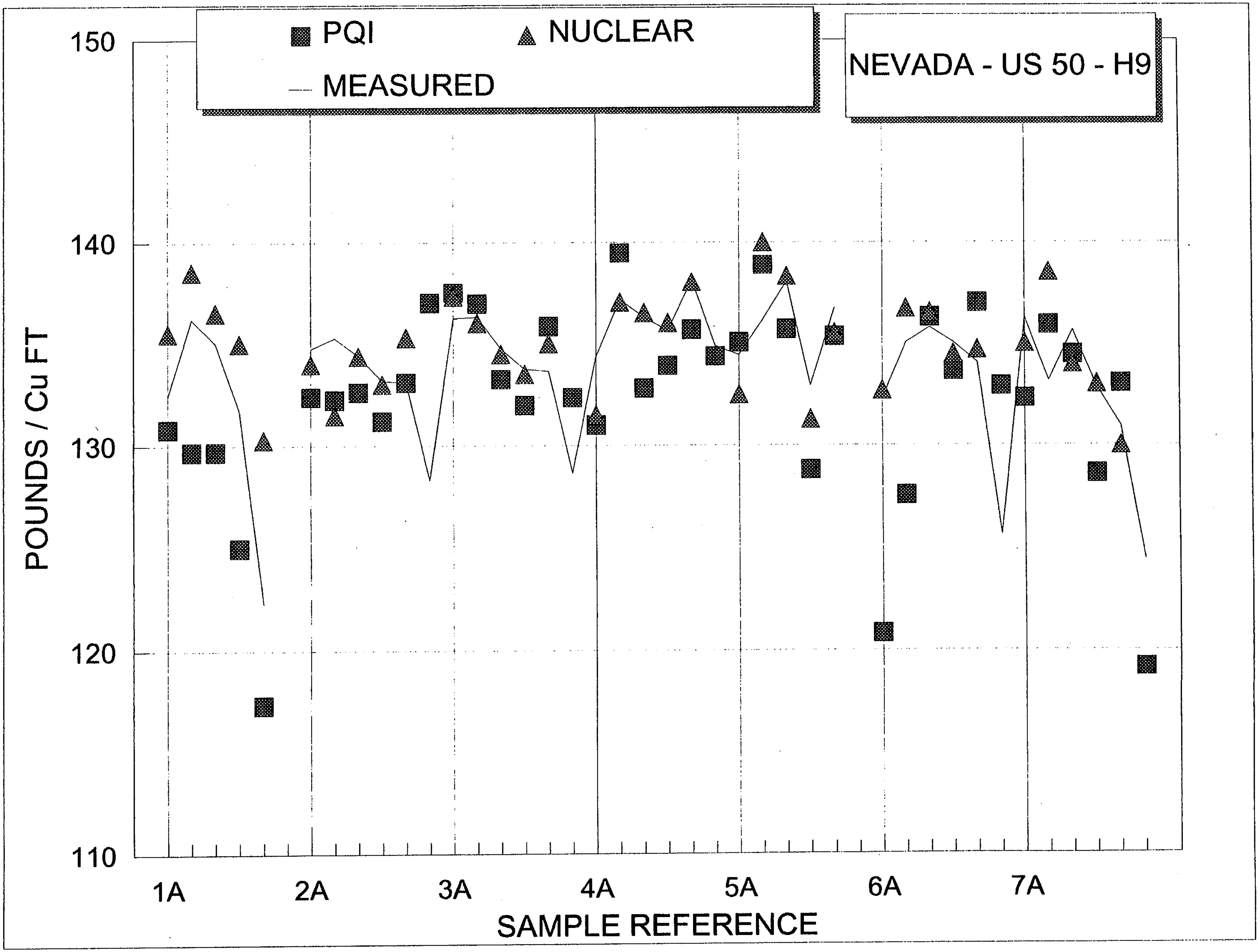




Attachment #5

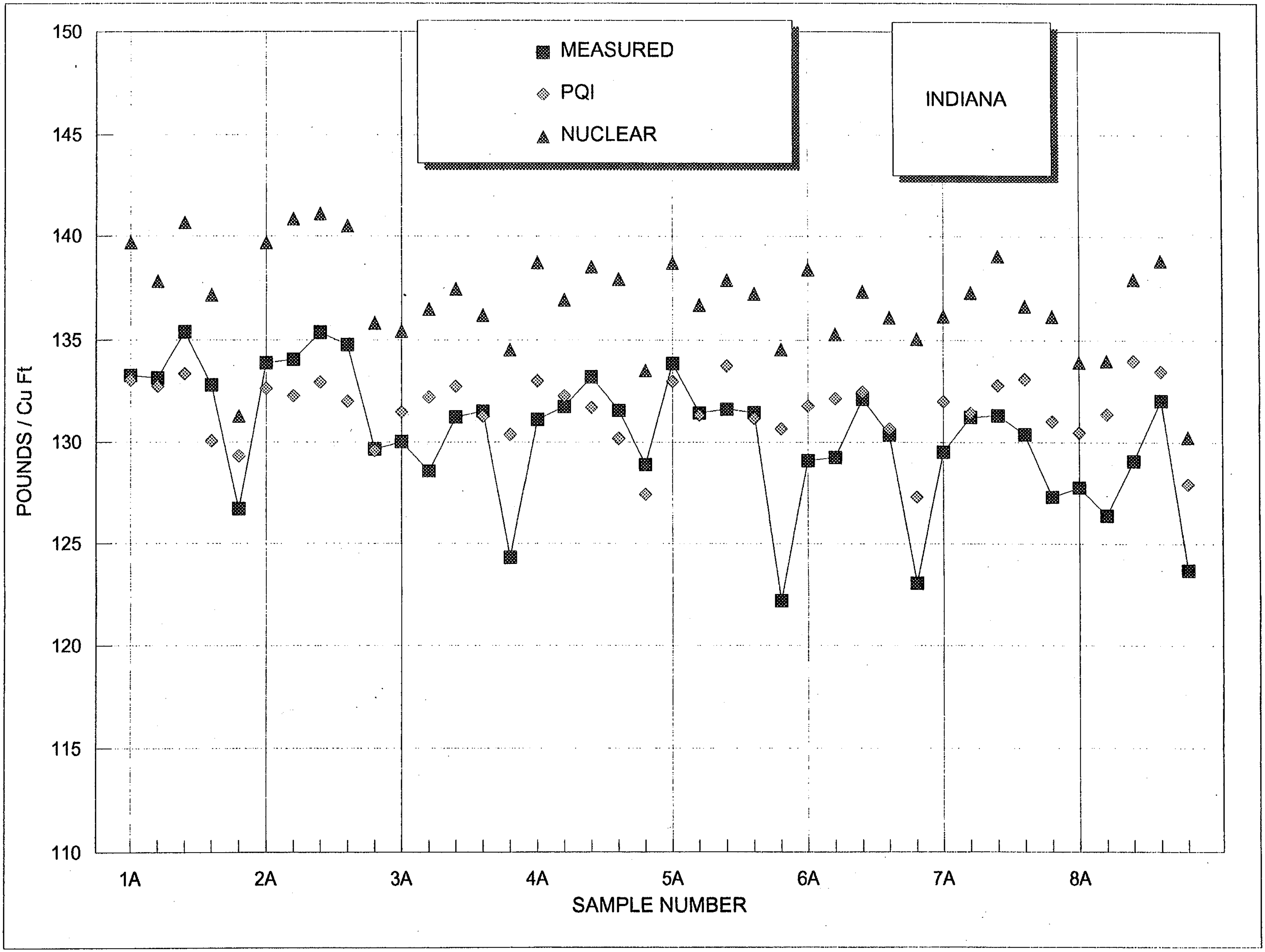


Attachment #6



Attachment #3

Attachment #8



ATTACHMENT #9
NCHRP - IDEA Project 32
+/- 2 lb./cu.ft. Error
Joint Data Included

Core Sample	Lower Tolerance Measure (Avge. Meas. - 2 lbs.)	Average Measure	Upper Tolerance Measure (Avge. Meas. + 2 lbs.)	PQI Average	Accept? 1=yes, 0=no	Nuclear Average	Accept? 1=yes,0=no
1A	131.7	133.7	135.7	133.1	1	139.7	0
1B	131.8	133.8	135.8	132.7	1	137.8	0
1C	134.2	136.2	138.2	133.4	0	140.7	0
1D	131.7	133.7	135.7	130.1	0	137.2	0
1J	125.3	127.3	129.3	129.3	1	131.3	0
2A	131.0	133.0	135.0	132.6	1	139.7	0
2B	132.5	134.5	136.5	132.3	0	140.9	0
2C	133.7	135.7	137.7	132.9	0	141.1	0
2D	134.1	136.1	138.1	132.0	0	140.5	0
2J	127.9	129.9	131.9	129.6	1	135.8	0
3A	128.1	130.1	132.1	131.5	1	135.5	0
3B	127.9	129.9	131.9	132.2	0	136.5	0
3C	129.8	131.8	133.8	132.7	1	137.5	0
3D	130.2	132.2	134.2	131.3	1	136.0	0
3J	122.2	124.2	126.2	130.4	0	134.5	0
4A	130.1	132.1	134.1	133.0	1	138.7	0
4B	130.7	132.7	134.7	132.3	1	137.7	0
4C	132.2	134.2	136.2	131.7	0	137.9	0
4D	131.0	133.0	135.0	130.2	0	133.5	1
4J	127.6	129.6	131.6	127.4	0	138.7	0
5A	132.1	134.1	136.1	133.0	1	138.7	0
5B	129.2	131.2	133.2	131.3	1	136.7	0
5C	130.9	132.9	134.9	133.8	1	137.9	0
5D	130.5	132.5	134.5	131.2	1	137.2	0
5J	121.2	123.2	125.2	130.7	0	134.6	0
6A	128.3	130.3	132.3	131.8	1	138.4	0
6B	128.5	130.5	132.5	132.1	1	135.3	0
6C	131.3	133.3	135.3	132.5	1	137.3	0
6D	128.7	130.7	132.7	130.7	1	136.1	0
6J	121.2	123.2	125.2	127.3	0	135.1	0
7A	127.7	129.7	131.7	132.0	0	136.2	0
7B	130.6	132.6	134.6	131.4	1	137.3	0
7C	129.6	131.6	133.6	132.8	1	139.1	0
7D	129.3	131.3	133.3	133.1	1	136.7	0
7J	125.6	127.6	129.6	131.0	0	136.2	0
8A	126.0	128.0	130.0	130.5	0	133.9	0
8B	124.8	126.8	128.8	131.4	0	134.0	0
8C	130.3	132.3	134.3	134.0	1	137.9	0
8D	130.0	132.0	134.0	133.5	1	138.8	0
8J	120.3	122.3	124.3	127.9	0	130.3	0
					58%		**3%**

ATTACHMENT #9
NCHRP -IDEA Project 32
+/- 2% Error
No Joints

Lower Tolerance Measure (Avge. Meas. - 2%)	Average Measure	Upper Tolerance TSI c/c (Column N+2%	PQI Average	Accept? 1=yes,0=no	Nuclear Average	Accept? 1=yes,0=no
131.0	133.7	136.3	133.1	1	139.7	0
131.1	133.8	136.5	132.7	1	137.8	0
133.5	136.2	138.9	133.4	0	140.7	0
131.0	133.7	136.4	130.1	0	137.2	0
130.4	133.0	135.7	132.6	1	139.7	0
131.8	134.5	137.2	132.3	1	140.9	0
132.9	135.7	138.4	132.9	1	141.1	0
133.4	136.1	138.8	132.0	0	140.5	0
127.3	129.9					
		0.0	131.5	1	135.5	0
127.3	129.9	132.5	132.2	1	136.5	0
129.1	131.8	134.4	132.7	1	137.5	0
129.6	132.2	134.8	131.3	1	136.0	0
129.4	132.1	134.7	133.0	1	138.7	0
130.0	132.7	135.3	132.3	1	137.7	0
131.5	134.2	136.9	131.7	1	137.9	0
130.4	133.0	135.7	130.2	0	133.5	1
131.5	134.1	136.8	133.0	1	138.7	0
128.6	131.2	133.9	131.3	1	136.7	0
130.2	132.9	135.6	133.8	1	137.9	0
129.8	132.5	135.1	131.2	1	137.2	1
127.7	130.3	132.9	131.8	1	138.4	0
127.9	130.5	133.1	132.1	1	135.3	0
130.6	133.3	135.9	132.5	1	137.3	0
128.1	130.7	133.4	130.7	1	136.1	0
127.1	129.7	132.3	132.0	1	136.2	0
129.9	132.6	135.2	131.4	1	137.3	0
129.0	131.6	134.3	132.8	1	139.1	0
128.7	131.3	134.0	133.1	1	136.7	0
125.5	128.0	130.6	130.5	1	133.9	0
124.2	126.8	129.3	131.4	0	134.0	0
129.6	132.3	134.9	134.0	1	137.9	0
129.4	132.0	134.6	133.5	1	138.8	0
				84%		**6%**

ATTACHMENT #9
NCHRP - IDEA Project 32
PQI
+/- 2.9 lb./cu.ft. Error
No Joints

Core Sample	Lower Tolerance Measure (Avge. Meas. - 2.9 lbs.)	Average Measure	Upper Tolerance Measure (Avge.Meas. + 2.9 lbs.)	PQI Average	Acceptable? 1=yes, 0=no
1A	130.8	133.7	136.6	133.1	1
1B	130.9	133.8	136.7	132.7	1
1C	133.3	136.2	139.1	133.4	1
1D	130.8	133.7	136.6	130.1	0
2A	130.1	133.0	135.9	132.6	1
2B	131.6	134.5	137.4	132.3	1
2C	132.8	135.7	138.6	132.9	1
2D	133.2	136.1	139.0	132.0	0
3A	127.2	130.1	133.0	131.5	1
3B	127.0	129.9	132.8	132.2	1
3C	128.9	131.8	134.7	132.7	1
3D	129.3	132.2	135.1	131.3	1
4A	129.2	132.1	135.0	133.0	1
4B	129.8	132.7	135.6	132.3	1
4C	131.3	134.2	137.1	131.7	1
4D	130.1	133.0	135.9	130.2	1
5A	131.2	134.1	137.0	133.0	1
5B	128.3	131.2	134.1	131.3	1
5C	130.0	132.9	135.8	133.8	1
5D	129.6	132.5	135.4	131.2	1
6A	127.4	130.3	133.2	131.8	1
6B	127.6	130.5	133.4	132.1	1
6C	130.4	133.3	136.2	132.5	1
6D	127.8	130.7	133.6	130.7	1
7A	126.8	129.7	132.6	132.0	1
7B	129.7	132.6	135.5	131.4	1
7C	128.7	131.6	134.5	132.8	1
7D	128.4	131.3	134.2	133.1	1
8A	125.1	128.0	130.9	130.5	1
8B	123.9	126.8	129.7	131.4	0
8C	129.4	132.3	135.2	134.0	1
8D	129.1	132.0	134.9	133.5	1
					91%

ATTACHMENT #9
NCHRP - IDEA Project 32
PQI
+/- 4.1 lb./cu.ft. Error
No Joints

Core Sample	Lower Tolerance Measure (Avge. Meas. - 4.1 lbs.)	Average Measure	Upper Tolerance Measure (Avge.Meas. + 4.1 lbs.)	PQI Average	Acceptable? 1=yes, 0=no
1A	129.6	133.7	137.8	133.1	1
1B	129.7	133.8	137.9	132.7	1
1C	132.1	136.2	140.3	133.4	1
1D	129.6	133.7	137.8	130.1	1
			4.1		
2A	128.9	133.0	137.1	132.6	1
2B	130.4	134.5	138.6	132.3	1
2C	131.6	135.7	139.8	132.9	1
2D	132.0	136.1	140.2	132.0	1
			4.1		
3A	126.0	130.1	134.2	131.5	1
3B	125.8	129.9	134.0	132.2	1
3C	127.7	131.8	135.9	132.7	1
3D	128.1	132.2	136.3	131.3	1
			4.1		
4A	128.0	132.1	136.2	133.0	1
4B	128.6	132.7	136.8	132.3	1
4C	130.1	134.2	138.3	131.7	1
4D	128.9	133.0	137.1	130.2	1
			4.1		
5A	130.0	134.1	138.2	133.0	1
5B	127.1	131.2	135.3	131.3	1
5C	128.8	132.9	137.0	133.8	1
5D	128.4	132.5	136.6	131.2	1
			4.1		
6A	126.2	130.3	134.4	131.8	1
6B	126.4	130.5	134.6	132.1	1
6C	129.2	133.3	137.4	132.5	1
6D	126.6	130.7	134.8	130.7	1
			4.1		
7A	125.6	129.7	133.8	132.0	1
7B	128.5	132.6	136.7	131.4	1
7C	127.5	131.6	135.7	132.8	1
7D	127.2	131.3	135.4	133.1	1
			4.1		
8A	123.9	128.0	132.1	130.5	1
8B	122.7	126.8	130.9	131.4	0
8C	128.2	132.3	136.4	134.0	1
8D	127.9	132.0	136.1	133.5	1
					97%

ATTACHMENT #9
NCHRP - IDEA Project 32
Nuclear
+/- 2 lb./cu.ft. Error, SSD
No Joints

Core Sample	Lower Tolerance SSD (SSD Avge. - 2 lbs.)	SSD Average	Upper Tolerance SSD (SSD Avge. + 2lbs.)	Nuclear Average	Accept? 1=yes,0=no
1A	140.4	142.4	144.4	139.7	0
1B	140.0	142.0	144.0	137.8	0
1C	141.8	143.8	145.8	140.7	0
1D	138.9	140.9	142.9	137.2	0
1J					
2A	142.2	144.2	146.2	139.7	0
2B	142.2	144.2	146.2	140.9	0
2C	142.6	144.6	146.6	141.1	0
2D	141.2	143.2	145.2	140.5	0
2J					
3A	134.7	136.7	138.7	135.5	1
3B	139.4	141.4	143.4	136.5	0
3C	141.9	143.9	145.9	137.5	0
3D	140.0	142.0	144.0	136.0	0
3J					
4A	139.7	141.7	143.7	138.7	0
4B	138.9	140.9	142.9	137.7	0
4C	140.9	142.9	144.9	137.9	0
4D	139.3	141.3	143.3	133.5	0
4J					
5A	141.0	143.0	145.0	138.7	0
5B	139.5	141.5	143.5	136.7	0
5C	140.4	142.4	144.4	137.9	0
5D	139.6	141.6	143.6	137.2	0
5J	165.6	167.6	169.6		
6A	139.4	141.4	143.4	138.4	0
6B	138.1	140.1	142.1	135.3	0
6C	139.3	141.3	143.3	137.3	0
6D	139.0	141.0	143.0	136.1	0
6J					
7A	139.9	141.9	143.9	136.2	0
7B	139.7	141.7	143.7	137.3	0
7C	141.1	143.1	145.1	139.1	0
7D	140.3	142.3	144.3	136.7	0
7J					
8A	138.3	140.3	142.3	133.9	0
8B	137.8	139.8	141.8	134.0	0
8C	140.8	142.8	144.8	137.9	0
8D	139.1	141.1	143.1	138.8	0
8J	135.8	137.8	139.8		0
					3%

ATTACHMENT #9
NCHRP - IDEA Project 32
Nuclear
+/- 2% Error, SSD
No Joints

Core Sample	Lower Tolerance SSD (SSD Avge. - 2%)	SSD Average	Upper Tolerance SSD (SSD Avge. + 2%)	Nuclear Average	Acceptable 1=yes,0=no
1A	139.6	142.4	145.3	139.7	1
1B	139.2	142.0	144.8	137.8	0
1C	141.0	143.8	146.7	140.7	0
1D	138.1	140.9	143.8	137.2	0
2A	141.4	144.2	147.1	139.7	0
2B	141.3	144.2	147.1	140.9	0
2C	141.7	144.6	147.5	141.1	0
2D	140.3	143.2	146.1	140.5	1
3A	134.0	136.7	139.4	135.5	1
3B	138.6	141.4	144.2	136.5	0
3C	141.1	143.9	146.8	137.5	0
3D	139.2	142.0	144.9	136.0	0
4A	138.9	141.7	144.6	138.7	0
4B	138.1	140.9	143.7	137.7	0
4C	140.0	142.9	145.7	137.9	0
4D	138.5	141.3	144.2	133.5	0
5A	140.1	143.0	145.8	138.7	0
5B	138.7	141.5	144.3	136.7	0
5C	139.5	142.4	145.2	137.9	0
5D	138.8	141.6	144.4	137.2	0
6A	138.6	141.4	144.2	138.4	0
6B	137.3	140.1	142.9	135.3	0
6C	138.4	141.3	144.1	137.3	0
6D	138.1	141.0	143.8	136.1	0
7A	139.0	141.9	144.7	136.2	0
7B	138.9	141.7	144.5	137.3	0
7C	140.3	143.1	146.0	139.1	0
7D	139.5	142.3	145.1	136.7	0
8A	137.5	140.3	143.1	133.9	0
8B	137.0	139.8	142.6	134.0	0
8C	139.9	142.8	145.6	137.9	0
8D	138.2	141.1	143.9	138.8	1
					13%

Attachment #10

Table 1 - Nuclear Density Meter Model List

Company	Model	Cost	Depth	NRC ?
BOART	MC-3	Portable Surface Moisture-Density Gauge $5,600	2 or 3 inches	Yes
HUMBOLDT	5001	Portable Surface Moisture-Density Gauge $5,000	3.4 inches	Yes
SEAMAN	C-75B	Portable Surface Moisture-Density Gauge $5,225	.75 to ? inches	Yes
SEAMAN	C-75B-A	Portable Surface Moisture-Density Gauge; alternate source, no NRC $5,975	.75 to ? inches	No; States vary
SEAMAN	C-200	Portable Surface Moisture-Density Gauge $6,975	.75 to ? inches	Yes
SEAMAN	C-200-A	Portable Surface Moisture-Density Gauge; alternate source, no NRC $7,425	.75 to ? inches	No; States vary
TROXLER	3440	Portable Surface Moisture-Density Gauge $5,800	4 or 6 inches	Yes
TROXLER	3430	Portable Surface Moisture-Density Gauge $4,850	4 or 6 inches	Yes
TROXLER	4640-B	Portable Surface Moisture-Density Gauge, Thin Layer $7,250	1 to 4 inches	Yes

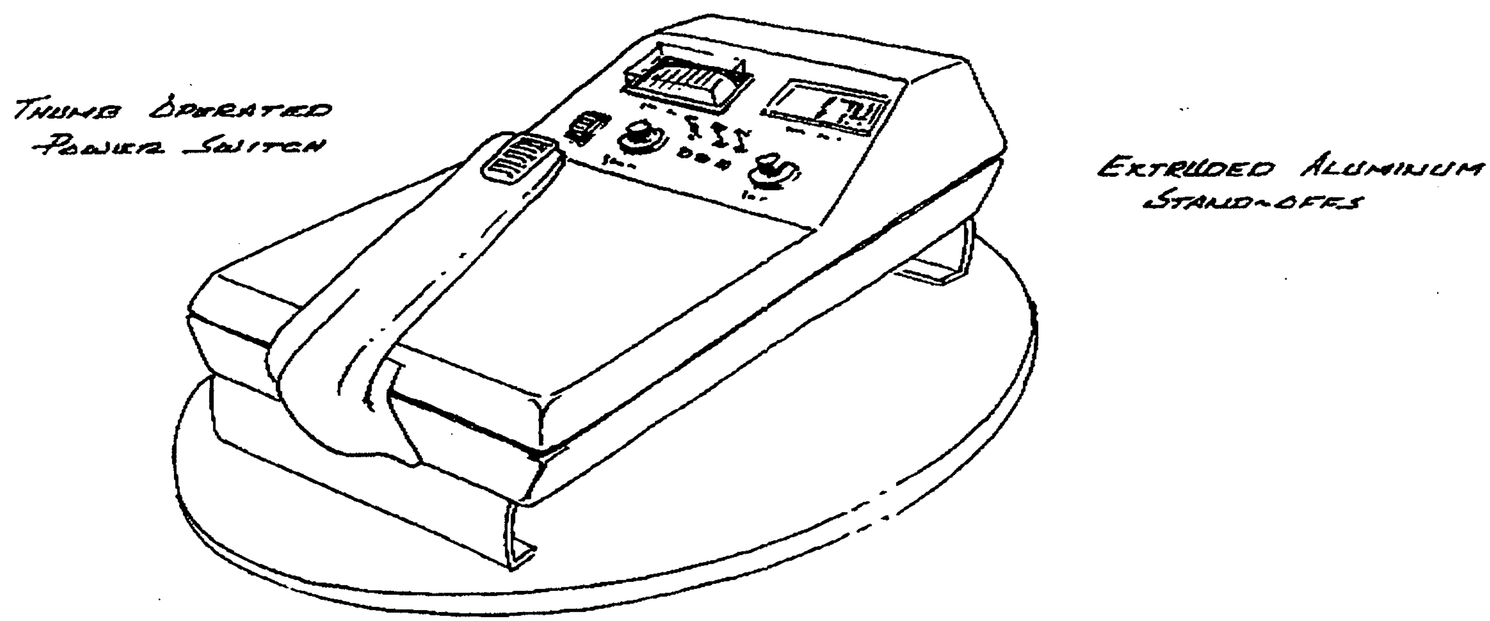
Table 2 - Nuclear Density Meters
Licensing, Training and Maintenance Costs

COMPANY	MODEL	NYSDOL LIC.	TNG @ MFG	TNG @ SITE	LOCAL TNG	CALIBRATION	LEAK TEST
BOART	MC-3	$565	?	Available	$125	?	$20
HUMBOLDT	5001	$565	$130	Available	?	$400-500	$12
SEAMAN	C-75B	$565	$150	Available	?	$200-300	$35
SEAMAN	C-75B-A	$565	$150	Available	?	$200-300	$35
SEAMAN	C-200	$565	$150	Available	?	$200-300	$35
SEAMAN	C-200-A	$565	$150	Available	?	$200-300	$35
TROXLER	3440	$565	$150	Available	$150	$225-450	$20
TROXLER	3430	$565	$150	Available	$150	$225-450	$20
TROXLER	4640-B	$565	$150	Available	$150	$225-450	$20

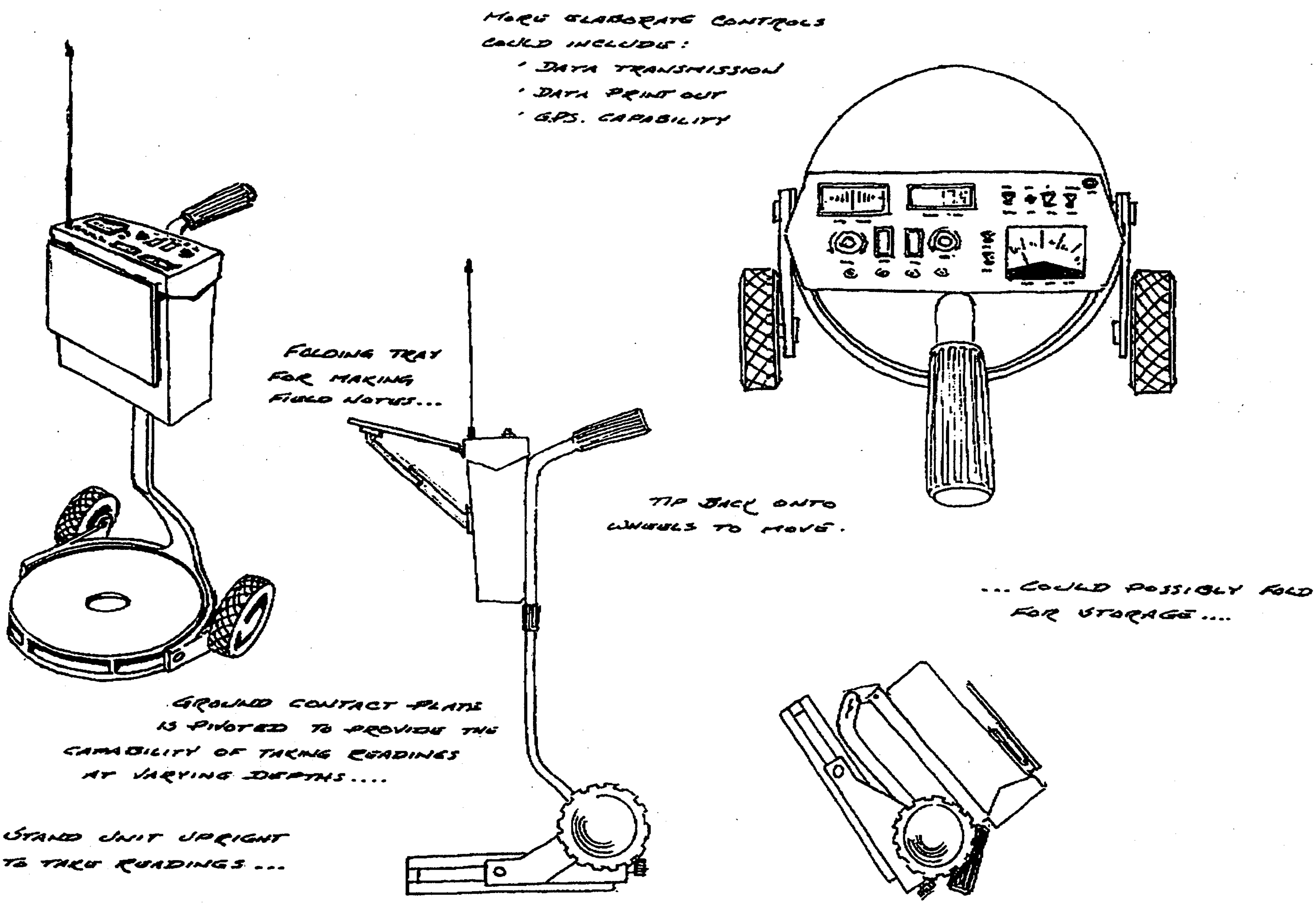
NOTES:

1. NYS DOL License fee is $1685 for 3 years.
2. Training costs are one-time costs.
3. NYS DOL license requires leak test every 6 months.
4. Manufacturers recommend calibration every 12-18 months.

Attachment #11



Trans Tech Services, Inc.
Pavement Quality Indicator



Trans Tech Services, Inc.
Pavement Quality Indicator