Louisiana Transportation Research Center

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Evaluation of Non-Destructive Density Determination for QA/QC Acceptance Testing

by

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Density is often considered one of the most important parameters for long-term pavement performance. Proper density specifications require the contractor and the Louisiana Department of Transportation and Development (DOTD) to follow quality control (QC) and quality assurance (QA) procedures. Contractors often utilize the nuclear density gauge (NDG) as part of their QC processes to monitor density (and soil moisture) for earthwork and unbound layers; and to establish rolling patterns for asphalt pavement layers. DOTD QA procedures require determination of density utilizing NDG for earthwork and unbound layers; and roadway core densities for asphalt pavement layers. However, nuclear technology in the NDGs requires extensive certifications and handling procedures; and the coring process is a destructive testing process to a freshly paved asphalt mat.

This research investigated the potential of low to non-nuclear devices with little to no radioactive footprint, to replace the NDG and roadway coring for asphalt and soils QA operations in Louisiana. The newly developed gauges are simple and easy to use and do not require extensive training, certifications, or lengthy paperwork; and are less destructive to the road. For this research, two separate field and lab evaluations took place: (1) LTRC's Geotechnical group evaluated the final density procedures for soils and (2) LTRC's Asphalt group evaluated the final density procedures for asphalt pavements.

The study determined the NDG to be a better option for DOTD in soils QA processes; and the non-destructive testing (NDT) for asphalt, a.k.a. thin-lift nuclear density gauge (TLNDG) and non-nuclear density gauge (NNDG), to be viable options for asphalt QA processes. The low-nuclear density gauge (LNDG) exhibited limitations of depth requirements and service life. The TLNDG and NNDGs were shown to have good correlation to core density results. NDT was determined to be safer, faster, better for the longevity of the pavement, and more economical for both contractors and DOTD.</td></tr>
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ABSTRACT

Density is often considered one of the most important parameters for long-term pavement performance. Proper density specifications require the contractor and the Louisiana Department of Transportation and Development (DOTD) to follow quality control (QC) and quality assurance (QA) procedures. Contractors often utilize the nuclear density gauge (NDG) as part of their QC processes to monitor density (and soil moisture) for earthwork and unbound layers, and to establish rolling patterns for asphalt pavement layers. DOTD QA procedures require determination of density utilizing NDG for earthwork and unbound layers, and roadway core densities for asphalt pavement layers. However, nuclear technology in the NDGs requires extensive certifications and handling procedures, and the coring process is a destructive testing process to a freshly paved asphalt mat.

This research investigated the potential of low to non-nuclear devices with little to no radioactive footprint, to replace the NDG and roadway coring for soils and asphalt QA operations in Louisiana. The newly developed gauges are simple and easy to use and do not require extensive training, certifications, or lengthy paperwork and are less destructive to the road. For this research, two separate field and lab evaluations took place: (1) LTRC's Geotechnical group evaluated the final density procedures for soils and (2) LTRC's Asphalt group evaluated the final density procedures for asphalt pavements.

The study determined the NDG to be a better option for DOTD in soils QA processes; and the non-destructive testing (NDT) for asphalt, a.k.a. thin-lift nuclear density gauge (TLNDG) and non-nuclear density gauge (NNDG), to be viable options for asphalt QA processes. The low nuclear density gauge (LNDG) exhibited limitations of depth requirements and service life. The TLNDG and NNDGs were shown to have good correlation to core density results. NDT was determined to be safer, faster, and better for the longevity of the pavement, and more economical for both contractors and DOTD.

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IMPLEMENTATION STATEMENT

DOTD currently utilizes the NDG for soils density acceptance and roadway cores for asphalt density acceptance. The use of NDGs for soils is expensive, requires specialized training and certifications, and requires specialized handling and storage. Coring asphalt pavements for density acceptance is destructive testing, and presents safety concerns, reduces sampling potential, delays results with testing, and creates early damage to a freshly paved mat. A desired outcome of this research was to provide Louisiana a safer and more efficient method for density QA acceptance.

Low to non-nuclear density gauges have been in development for over a decade around the country and are increasing in technology/accuracy. Construction contractors have been using these devices in their QC procedures. This research evaluated the accuracy of these devices and to provided recommendations regarding the use of these devices for the DOTD QA procedures.

The findings of this research have led to the development of supplemental specifications to the 2016 Louisiana specifications (Appendix C) to permit use of non-destructive testing devices for QA procedures in asphalt construction. The specifications outlined new testing and density QA acceptance procedures.

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INTRODUCTION

Density of soil and asphalt layers is often considered the most important variable in the construction of durable, longer-lasting roads. The compaction of particles in soil and asphalt layers increases the surface-to-surface contact and inter-particle friction, resulting in higher stability and improved stiffness and strength *[1]*. To meet density requirements, contractors and transportation agencies follow quality control (QC) and quality assurance (QA) procedures to ensure specifications are met, and performance is achieved. According to Louisiana's Quality Assurance Manual (QAM), quality control is defined as the process used by the Contractor to monitor, assess, and adjust material selection, production, and project construction to control the level of quality so that the product continuously and uniformly conforms to specifications. Quality assurance is defined as the combined efforts of quality control and acceptance processes to assure that a project will provide the public with a durable product exhibiting a high level of performance and is the responsibility of the Louisiana Department of Transportation and Development (DOTD) *[2]*. A quality assurance program provides a level of confidence that the finished product will meet standards. The QC/QA aim for density on a soils layer is normally above 95 percent compaction compared to the maximum dry density, while hot-mix asphalt pavement is 92 to 93 percent. If a pavement has low density, e.g., less than 94 percent for soil layers or less than 91 percent for asphalt layers, premature pavement distresses may result. These distresses may be in the form of premature oxidation aging, increased cracking, rutting, structure weakening, raveling or stripping *[1]*.

For soil construction, contractors utilize their nuclear density gauge (NDG) as part of their QC process to monitor density and soil moisture. DOTD utilizes their similar nuclear devices for QA processes for soil layers by measuring density, every 1000 feet or so, for final acceptance. For asphalt pavement construction, contractors utilize the NDG to establish rolling patterns for asphalt pavement construction, while final density acceptance requires the in-place density of HMA pavements to be measured from core samples cut from the pavement after compaction. While the NDG and roadway cores are known to be the most precise methods to determine densities, these procedures have their limitations.

NDGs operate with the use of radioactive materials that may be hazardous to the health and well-being of operators. This requires all operators to attain prior radiation safety training, and maintain current applicable safety certification. Dosimeter badges are required for personal monitoring during use. Along with operation guidelines, routine procedures such as source leak tests and annual calibration are recommended to maintain the gauges. Strict licensing and re-licensing, record-keeping usage, storage, and eventual disposal of the gauges are all complications of using the nuclear gauges' technology. Additionally, transporting radioactive materials are subject to rules and regulations *[3-7]*.

For the asphalt coring process, drilling cores creates damage to the new pavement and, though the holes are later patched, imperfections in the pavement can form causing long-term distresses such as cracks and potholes. Additionally, measuring cores generally takes time, as core results are typically not available until the next day or even longer, in order for the pavement to have enough time to be laid and cooled. This amount of time is too long to allow for corrections in the paving process and compaction efforts. The required use of laboratory equipment is also a cost factor to be considered. A minimum of one full-time lab technician is usually required to conduct all the tests. Furthermore, only a small number of cores are used to represent the density across several miles of pavement. This small sample size potentially leads to the core result not fully representing the density of the a pavement section *[3-7]*.

Subsequently, there is a high demand for a device that is accurate, easy to use, quick, non-destructive, and nonradioactive. Contractors and DOTD are interested in the potential of the low to non-nuclear gauges to overcome disadvantages of the NDG and core sample method. Recently, several asphalt contractors have made the switch to non-nuclear gauges for their quality control procedures. Previous research has shown that low to non-nuclear gauge methods could benefit by offering economic savings, faster data measurement, no intense federal regulations, lesser safety concerns, no extra licensing and intense training, improved calibration techniques, non-destructive testing, faster testing times, and increased density measurements throughout the entire paving project. The ability of these gauges to instantaneously read asphalt pavement density creates a cost-effective opportunity to significantly increase the number of density readings taken on the highway during construction, providing real-time feedback to the paving crew for instantaneous corrective action. Additionally, the new gauges may also significantly reduce the current core sampling and laboratory analyses that are used to monitor asphalt pavement densities. Development of these gauges in the pavement construction industry should yield more efficient paving operations, higher productivity, and better quality control, resulting in longer pavement lifetimes and lower overall life-cycle costs. In order to accept these non to low-nuclear gauges, their accuracy and effectiveness should be proven equivalent to or better than nuclear gauges and to core density measurements *[3-7]*.

Density Gauge Comparisons

The NDG and low-nuclear density gauge (LNDG) measure density by emitting gamma rays from a cesium source. The newer technology in the LNDG emits less radiation as it has a smaller source. These rays pass through the compacted material to detectors, as seen in Figure 1. For a densely compacted material, the gamma rays do not easily pass through to the detector, resulting in a low number of counts. Less dense materials allow the gamma rays to pass through to the detectors more readily, resulting in a higher number of counts.

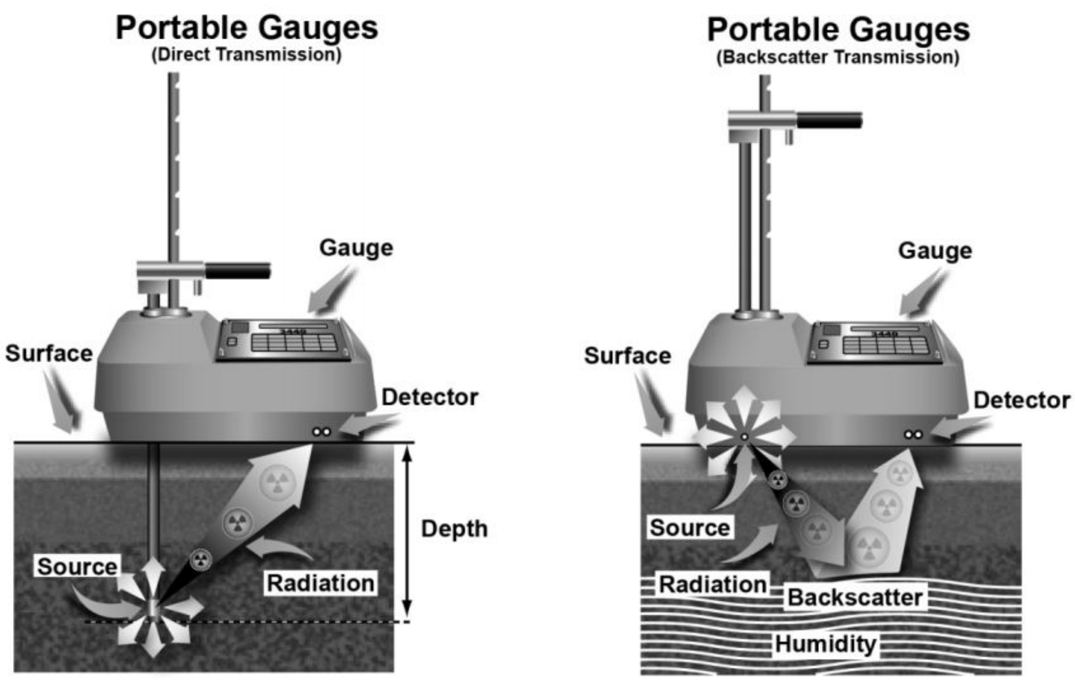

Figure 1
NDG schematic – direct vs. backscatter transmission

The non-nuclear density gauges (NNDG) for asphalt generate an electromagnetic field under the device and measure bulk density, or the degree of compaction, by the response of the electrical sensing field versus changes in electrical impedance of the layer as shown in Figure 2. This measurement is a function of the composite resistivity and dielectric constant of the asphalt material. Because different asphalt elements have different levels of resistivity and different dielectric properties, the unit is first calibrated to the asphalt material being measured. Once calibrated, the density may be measured directly. Currently, the electromagnetic field is a repeatable, semi-toroidal volume. Simply stated, the electromagnetic gauge will yield roughly the same result when a test is conducted in the same location, repeatedly.

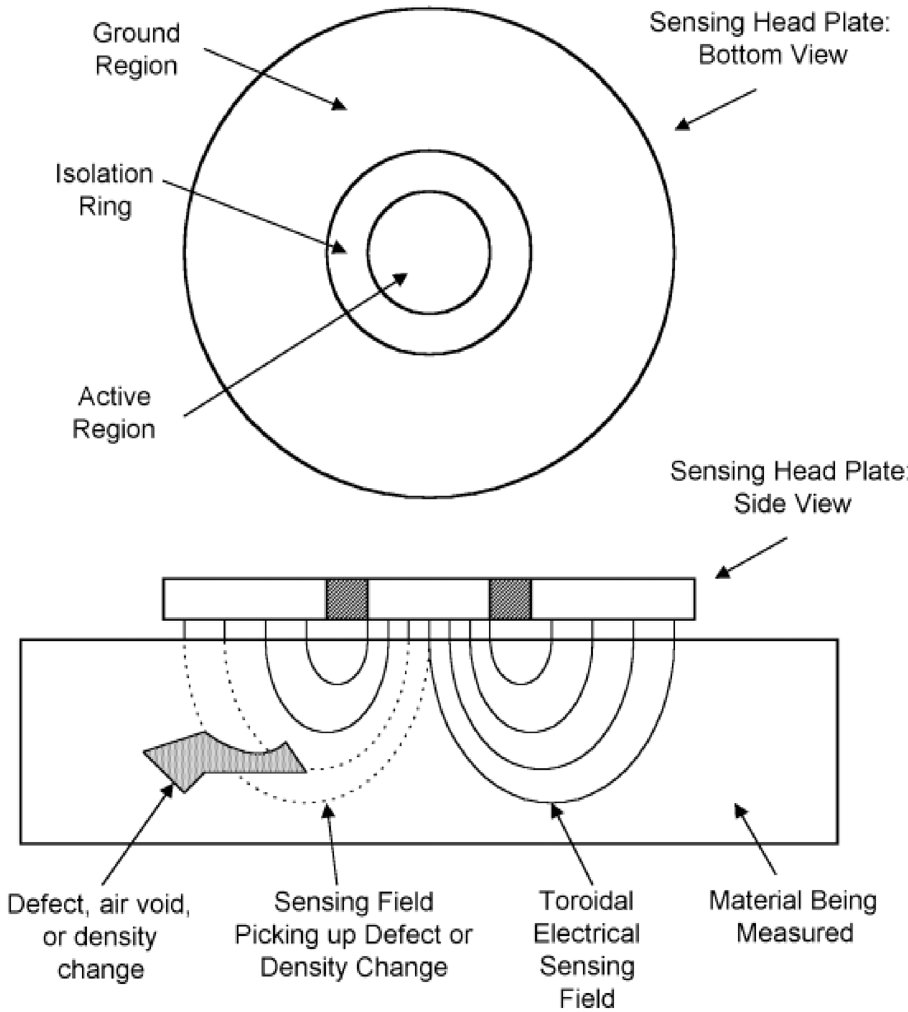

Figure 2
Typical NNDG schematic

Early models of NNDGs demonstrated poor correlations with traditional density measurements and were significantly affected by factors such as temperature and moisture. Several early studies did not recommend use of the NNDGs for QA testing *[8-9]*. However, as technology advanced, improvements were made to make them more accurate, later studies found the device was acceptable for QA as long as proper procedures and offsets were applied *[3-7]*.

OBJECTIVE

LTRC's Geotechnical and Asphalt groups conducted two separate field and laboratory evaluations. The Geotechnical group evaluated field densities of soil layers and the Asphalt group evaluated field densities on asphalt pavement layers.

The first objective of this research was to conduct a validation study to compare the new LNDG and moisture probe, for soil density and moisture determination compared to the density readings of conventional NDGs for the geotechnical group. The asphalt group compared density results from a NNDG and NDG against roadway cores. Additionally, the research will evaluate the nuclear and low/non-nuclear gauge as QA devices for non-destructive density determination. The research will utilize intensive field tests and core samples to determine their effectiveness benefits, and implementation potential for QA/QC applications within DOTD.

SCOPE

Geotechnical

LTRC's Geotechnical group went to two sites for moisture/density gauge comparisons. Two types of non-destructive density gauges were evaluated. The first was the currently utilized nuclear density gauge (NDG) and the second was a newer lower nuclear sourced density gauge, labeled low-nuclear density gauge (LNDG) in the report. The moisture and density readings of the devices were compared to the moisture and density readings provided by a conventional NDG. Other elements were evaluated including performance, cost, reporting, training requirements, etc.

Asphalt

LTRC's Asphalt group conducted field evaluations on seven asphalt projects around Louisiana with a nuclear and a non-nuclear density gauge. Two additional field sites were conducted by a contractor with similar devices. In total, 11 different asphalt lifts were evaluated utilizing a nuclear and a non-nuclear density gauge; and the density results were compared with corresponding roadway cores. Roadway core densities were determined by AASHTO T-166 (DOTD TR 304-03), "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens." The asphalt field evaluation involved utilizing two nuclear and two non-nuclear density gauges. The two nuclear gauges included a full depth (NDG) and thin-lift density gauges (TLNDG). It was recommended during the middle of the research to utilize a TLNDG for more accurate measurements as the NDG recorded underlying layers which produced inaccurate density readings. The two non-nuclear gauges were labeled in the report as non-nuclear density gauge 1 (NNDG-1) and 2 (NNDG-2). Additionally, for further simplicity in this report, project site identifications were abbreviated to location and type of lift. Example is LA98BC stands for location at LA 98 and the asphalt lift examined that day was the binder course. Similar to the geotechnical group, the density readings of two devices were compared to the density readings provided by LTRC's conventional NDG and TLNDG. Other elements were evaluated including performance, cost, reporting, training requirements, etc.

METHODOLOGY

Validation of the research was completed with the assistance of asphalt contractors, DOTD, and gauge suppliers. A thorough literature review was conducted to understand what other states have considered with the NDG, TLNDG, and NNDG.

Lab work included the determination of density of the asphalt pavement cores. Statistical analysis was conducted to determine the accuracy and effectiveness of the impedance gauges in comparison to the nuclear moisture-density gauge and core measurements currently utilized by the DOTD. Analysis of variance (ANOVA) was used to compare the devices. Additional statistical evaluation was used to recommend an adequate QA sampling plan for non-destructive density determination for non-destructive methods.

Devices

Geotechnical

The Geotechnical group operated a Troxler NDG, Model 3440, and Troxler LNDG, EGauge Model 4590 with separate moisture probe, Model 6760 The LNDG utilizes a low activity gamma ray source to perform the density measurements in the same way that a traditional nuclear gauge would. However, the source is much smaller and not within "reportable" limits. The separate moisture probe of the LNDG utilizes an electromagnetic source to measure moisture, using the same hole that is prepared for density measurements. The moisture probe transfers the moisture data to the LNDG via Bluetooth® technology (or a cable) to provide full moisture-density results.

Field projects with embankment, subbase, or base course work were evaluated with the NDG and the LNDG. Sites utilized by recent LTRC project,16-6GT, were also utilized by this research as equipment-induced variations is a common goal; and since 16-6GT already had a test matrix established. Figure 3 shows the devices utilized for non-destructive density determination for soil density projects. The NDG is the yellow gauge on the left, while the LNDG is the white gauge paired with the moisture probe on the right.

Figure 3
Soil density gauges (NDG on left; LNDG on right)

Asphalt
The Asphalt group evaluated the NNDGs developed by Troxler Electronic Laboratory and TransTech Systems. The NNDGs utilized were the PaveTracker Model 2701B and PQI Model 380. The devices function similarly to the NDG; however, the devices do not utilize radioactive material for density measurements, instead they utilize electrical impedance technology to determine density of materials. Non-destructive methods for the measurement of HMA density offer the ability to take numerous density readings in a very short period. Non-nuclear methods reduce or eliminate the need for intensive licensing, training, and maintenance efforts common to nuclear gauges. Likewise, these gauges may eliminate the use of coring for density QA purposes. The NNDGs were compared with a NDG and TLNDG for density correlations. Figure 4 shows the most prevalent devices utilized for non-destructive density determination for asphalt density projects; the TLNDG is furthest left. The two NNDGs are center and right.

Figure 4
Asphalt density gauges

Geotechnical Test Plan

Sites

Soil testing was conducted on LA 98 (State Project Number H.012128) located in Roberts Cove, Louisiana as shown in Figure 5. Density measurements were taken on the 10-in. thick layer of in-place cement stabilized base course treated with 7 percent cement. Readings were taken at Stations 266+00 and 267+00 in the test layout plan shown in Figure 6. The test plan intended that NDG and LNDG tests be conducted in each area (A through E) using the test layout, rotating the NDG and LNDG device between measurements in a 120° angle pattern.

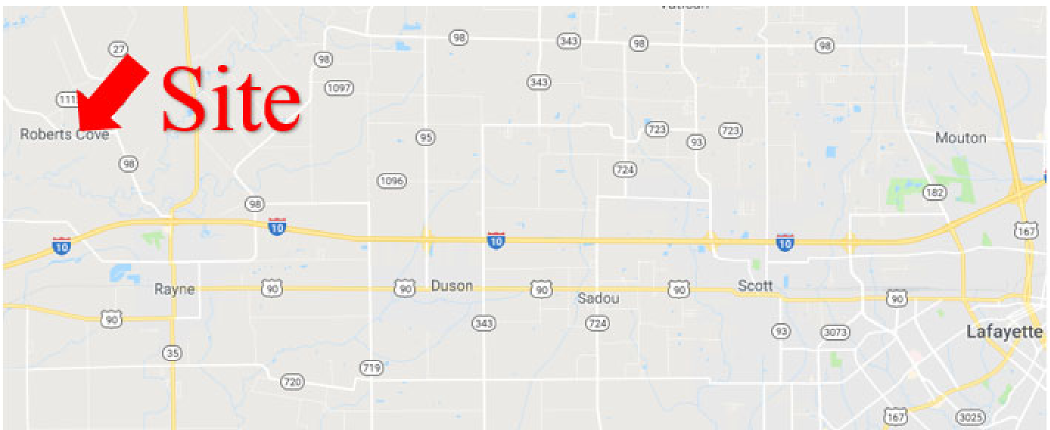

Figure 5
LA 98 site plan

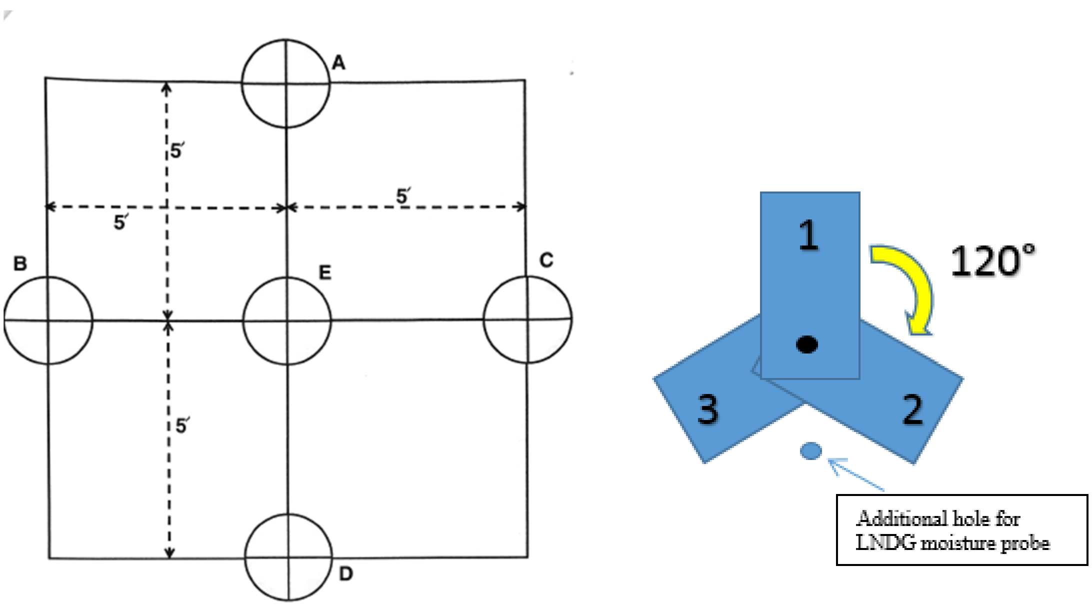

Figure 6
Area layout and test layout

Testing was also conducted at the LTRC Pavement Research Facility (PRF) located in Port Allen, Louisiana as shown in Figure 7. Three testing areas were constructed at the site (A, B, and C). Test section A was treated with 7 percent lime and 15 percent fly ash at a soil layer thickness of 12 in. Test section B was treated with 5 percent lime and 11 percent fly ash at a soil layer thickness of 12 in. Test section C was treated with 2.5 percent lime and 2 percent cement at a soil layer thickness of 12 in. Readings for all test sections were taken at designated locations.

Figure 7
LTRC Pavement Research Facility (PRF)

Test Procedure

For the NDG the following test procedures were utilized. After turning the gauge on, the gauge performed a 5-minute self-test. Then, each day before taking readings, technicians performed a standard count to determine that the gauge was working properly; and to adjust for source decay and environmental influences. During the standard count (4 minutes), the gauge is placed on the standard Teflon block and placed at least 33 ft. away from any other nuclear source.

At the designated test location, the surface was prepared, as smooth as hand possible with the scraper plate. Then the extraction tool was placed over the guide post and the drill rod was placed in the guide post. The drill rod was hammered to 2 in. below the desired depth of measurement. All measurements were taken at a 6-in. depth. Using the extraction tool, the drill rod was pulled straight up from the ground being careful not to damage the hole. The source rod of the nuclear gauge was lowered to the desired depth of measurement and placed in the pre-hammered hole. Readings were taken using the direct measurement method. After testing, the nuclear gauge beeps signifying one complete reading. DOTD TR 401 requires three measurements from the same hole, so the device is spun in the same hole to collect an average of measurements. The NDG and LNDG were turned 120° during their separate measurements to perform the second reading, then turned an additional 120° to perform the third and final reading. For each designated location, three measurements were taken and the average was calculated.

Readings with the LNDG were taken in the same hole as the NDG. In preparation for testing with the LNDG the following procedures were utilized. After turning the LNDG on, self-testing only took two seconds, however five minutes were allowed for the gauge to warm up. During all testing with the LNDG, the NDG was stored at least 33 ft. away so that the nuclear source did not interfere with the LNDG. Before taking readings, the LNDG was calibrated by taking a reading on the surface of the material to be tested. Each calibration reading took approximately 4 minutes.

The same procedure was utilized for the LNDG as the NDG regarding insertion and rotation. The LNDG utilized the same hole as the NDG testing.   However, at the designated test location, an additional hole was created to insert the LNDG moisture probe to speed testing, connect the moisture test to the density measurement, and preserve the hole integrity for the moisture probe, which was a larger diameter than the nuclear rod; since the moisture probe requires direct soil contact. All measurements moisture probe holes were opened to a 6-in. depth. The moisture probe (connected to the LNDG via a cable) inserted into its hole allowed simultaneous density and moisture readings. The LNDG in its hole was turned 120° to perform the second reading while the moisture probe remained in its hole. Upon completion of the LNDG and moisture probe readings, density and moisture readings were provided. For each designated location, three measurements were taken and the average was calculated.

Asphalt Test Plan

LTRC Research Sites

LTRC asphalt research group obtained density gauge readings and cores from seven asphalt paving sites (nine asphalt mixtures/lifts) in Louisiana. These sites were visited from March 2017 to March 2018. Table 1 shows each sites location, project number, dates, type of construction, mix type, asphalt mat thickness, nominal maximum aggregate sizes (NMAS), and air temperature at time of construction. The sites included low volume, two-lane highways, to high-volume, interstates, which allowed evaluation a variety of mat thicknesses and mix designs. Additionally, since the projects were spread throughout the year, this allowed for evaluation in different weather climates.

Table 1
List of LTRC research sites

Project Location	*Project No.*	*Date of Density Readings*	*Type of Construction*	*Mix Type*	*Mat Thickness (in.)*	*NMAS Size*	*Air Temp. (°F)*
Thibodaux	*H.012291*	*3/23/2017*	*Stabilize Base & Asphalt Overlay*	*Binder*	*3*	*19*	*67*
US 90	*H.009658*	*4/6/2017*	*Mill and Overlay*	*Wearing*	*2*	*12.5*	*60*
I-20	*H.010480*	*6/28/2017, 6/29/2017*	*Mill and Overlay*	*Binder*	*6*	*25*	*90*
US 90	*H.011327*	*7/26/2017*	*Mill and Overlay*	*SMA*	*2*	*12.5*	*85*
I-12	*H.010558*	*10/18/2017*	*New Pavement (Widening)*	*Binder*	*6*	*25*	*82*
LA 98	*H.012128*	*11/27/2017*	*Stabilize Base & Asphalt Overlay*	*Binder*	*3*	*19*	*71*
US 190	*H.009549*	*12/21/2017, 12/29/2017, 2/1/2018*	*Mill and Overlay*	*Binder & Wearing*	*2*	*19*	*54*

Contractor Research Sites

With the assistance of a Louisiana asphalt contractor, additional cores and density gauge data were acquired for LTRC analysis. Two additional asphalt paving projects, located on I-20 and LA 485, and their respective information are displayed in Table 2.

Table 2
Contractor research sites

Project Location	Project No.	Type of Construction	Mix Type	Mat Thickness (in.)
I-20	H.010480	Mill and Overlay	Binder	6
LA 485	H.011594	Mill and Overlay	Binder	2

Test Procedures

The LTRC asphalt research group gathered density readings with four density gauges, a NDG, a TLNDG and two NNDGs (NNDG-1 and NNDG-2). The NDG was used in the first three asphalt project sites and the TLNDG was utilized for the remaining asphalt project sites. The TLNDG was deemed a more accurate nuclear gauge to use for thin asphalt layers (4 in. and less).

The first step for field test procedures was gauge setup. Similar procedures as the soils group were performed before taking readings for the NDG and TLNDG. A standard count was performed each day the gauge was used to check to ensure the gauge was working properly and to adjust for source decay and environmental influences. During the standard count (4 minutes), the gauge was placed on the standard block and placed at least 33 ft. away from any other nuclear source. Readings were taken using the back-scatter measurement method. The maximum theoretical density (G_{mm}) was inputted in the NDG to obtain percent compaction result. The NNDGs were turned on inside their respective transport containers where a calibration plate could determine if the gauges were operating precisely. Project ID, G_{mm}, mix type and mat thickness were inputted into each NNDG before any readings, but no slope or offset was set during field readings.

Figure 8 displays a typical test setup for asphalt projects. A minimum of five density spots were obtained from each site for density gauge and core comparisons. An 18-in. circle was the designation point for every density reading. At the designated test location, 2 NDG or TLNDG measurements were obtained at 30 second counts each. After the first reading, the gauge was turned 180° to perform the second reading; the two measurements were then averaged. NNDG readings were taken utilizing the 5-point cloverleaf pattern. Offset of each density gauge was calculated later during data analysis. Majority of the asphalt density gauge readings were taken at time of construction, while the mat was still warm.

Additionally, some readings were taken at a later date to allow the mat to cool, with the purpose to determine differences in density readings from mat temperature. Proper gauge procedures, such as gauge placement and cleaning, were followed when obtaining field readings. Coring either took place the day of paving or the next day. If coring was done on the same day, ice bags were laid on the spots to cool the spots before coring. All cores were trimmed to proper thicknesses for more precise density results. AASHTO T-166 “Bulk Specific Gravity of Compacted Asphalt Mixtures” procedures were conducted at LTRC asphalt lab on all cores collected from the paving sites *[10]*.

Figure 8
Typical asphalt test site

For the site data collected by the contractor, I-20 and LA 485, readings were taken with a TLNDG and a NNDG-1. TLNDG and NNDG-1 readings were taken at core locations for comparison and the data was shared to LTRC asphalt research group. The contractor similarly conducted all readings from an 18-in. circle, where a spot and average reading were obtained with the density gauge. Cores were obtained the next day.

Sand patch testing was implemented mid-research to further determine impact of surface texture had to the density readings of the gauge. As seen in Figure 8, sand patch testing was conducted at each density reading spot. Testing was done either inside the circle or just outside depending if a cool spot was needed just before coring.

Data collected by the LTRC asphalt group and contractor were analyzed utilizing linear regression and analysis of variation (ANOVA) calculations.

DISCUSSION OF RESULTS

Geotechnical Results

Site Data and Analysis

Table 3 contains the summary for results of the test sites at LA 98 and at PRF in Table 3. The comparisons of densities and moisture content of both the NDG and the LNDG are shown below. For more in-depth results and site data, refer to Appendix A.

Table 3
Dry density and moisture content of the NDG and LNDG

Dry Density (pcf)			Moisture Content (%)	
NDG	LNDG		NDG	LNDG
76.6	76.4		30.9	33.1
76.8	68.2		31.7	48.0
75.1	75.9		32.0	37.5
78.2	74.4		28.8	36.9
84.0	92.0		28.0	18.9
80.2	95.8		24.2	19.4
95.4	98.3		19.8	21.8
96.2	93.0		18.2	21.3
92.9	94.2		17.9	24.3
89.4	92.0		19.2	27.0
99.5	105.9		17.6	15.3
100.3	102.4		18.2	16.2
99.3	99.3		17.8	16.6
105.1	105.5		13.2	15.3
99.1	104.8		17.1	16.3
101.7	107.5		17.0	18.8
101.2	107.4		18.9	20.8
102.3	107.6		17.2	20.1
106.5	110.0		13.8	15.1
98.4	96.5		17.6	21.5

Figure 9 illustrates a one-to-one comparison of NDG dry density to LNDG dry density and returned an R^2 value of 0.84. This indicates that the LNDG can produce dry density results that compare favorably to the NDG. Figure 10 illustrates a one-to-one comparison of LNDG moisture content to NDG moisture content and returned an R^2 value of 0.67. This indicates that the LNDG produces similar, but slightly wetter moisture content results than the NDG.

In many instances, moisture content in the field is obtained through a secondary process (e.g., hot plate method), so the accuracy of this measurement is not as critical as the dry density.

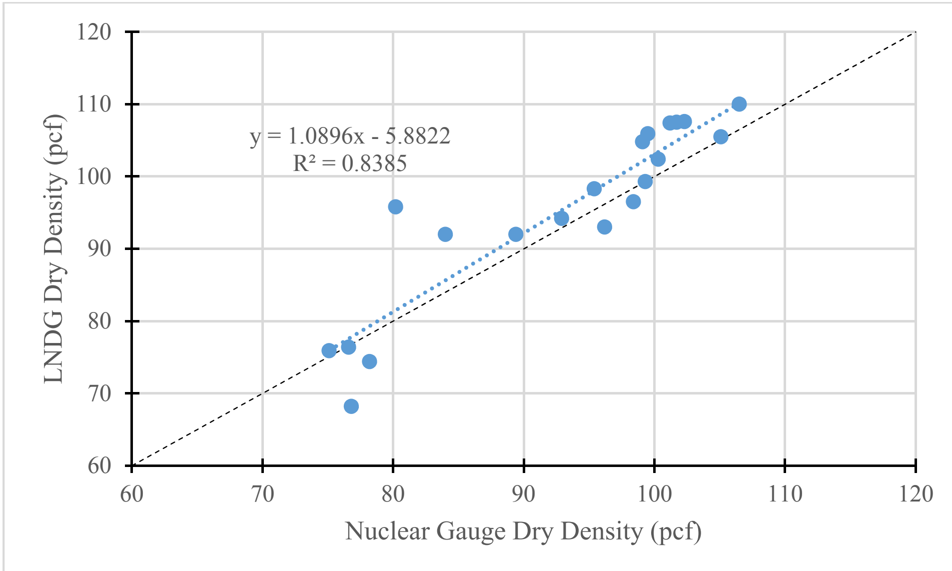

Figure 9
Comparison of dry density between NDG and LNDG

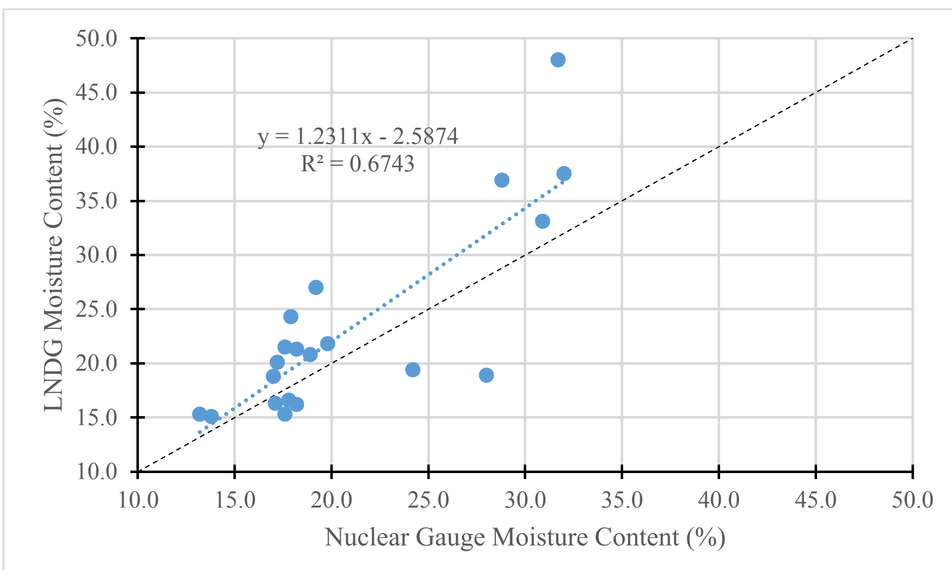

Figure 10
Comparison of moisture content between NDG and LNDG

Density Gauge Comparison and Cost Analysis

Device literature and field experience indicated that penetration of the LNDG is limited to 8 in. as compared to the NDG at 12 in. *[11]*. This depth limitation could likely limit the use of the LNDG on DOTD layers that have thicknesses of 12 in. DOTD specifications allow 12-in. thick layers in materials like embankment and class II stone base course. To measure the density of these layers the NDG is set at 10 in. per DOTD test method. The LNDG would have only a maximum depth of 8 in. which would leave a third of the layer unchecked for density and moisture, in contrast to the TR401 note for the NDG that states: ***TR401, Note A-9:*** *The test depth shall be the deepest setting possible that will not penetrate beneath the lift of material being tested.*

The department has over 100 NDGs across the state. Table 4 shows a list of the NDG within DOTD. These devices have a variety of ages and are mostly sunken cost to the department. As an example, the LTRC device was purchased in 1987 and still functions. A new NDG is roughly $3,400. Current NDG devices are occasionally traded in to Troxler for replacements; however, this occurrence is rare and depends on the vendor for the amount of credit received on each device. In contrast, the LNDG device cost LTRC approximately $15,000, and the trade in value would be $2,500 for the NDG.

Table 4
Number of DOTD NDGs

District 02	**New Orleans**	11
District 03	**Lafayette**	**16**
District 04	**Shreveport**	**14**
District 05	**Monroe**	**12**
District 07	**Lake Charles**	**10**
District 08	**Alexandria**	**15**
District 58	**Chase**	**7**
District 61	**Baton Rouge**	**12**
District 62	**Hammond**	**9**
LTRC		**1**
Total		107

Table 5 shows the devices with parameters for comparison. The table includes some cost information for the badges and licenses. These costs total to roughly $10K, annually for the NDG. Both devices would likely require time and energy to purchase and maintain; a transition to the LNDG devices would likely entail some overlap of devices to ensure continuity – one of each device type with a possible sunset date to allow for training and implementation.

Table 5
Device comparison – measurements and costs

<table>
<tr><th>Parameter/Device</th><th colspan="2">NDG</th><th colspan="2">LNDG</th><th>Moisture Probe</th></tr>
<tr><td>Device Type</td><td colspan="2">Conventional NDG</td><td colspan="2">Low-Activity NDG</td><td>Moisture Probe</td></tr>
<tr><td>Measurement</td><td colspan="2">Wet Density and Moisture</td><td colspan="2">Wet Density only</td><td>Moisture only</td></tr>
<tr><td>Depth of Probe
Diameter</td><td colspan="2">Up to 12 in.
0.630 in.</td><td colspan="2">Up to 8 in.
0.630 in.</td><td>Up to 5.5 in.
0.750 in.</td></tr>
<tr><td>Density Determination</td><td colspan="2">Gamma-ray Compton Scattering</td><td colspan="2">Gamma-ray Compton Scattering</td><td>Not Applicable (NA)</td></tr>
<tr><td>Device Source (half-life)</td><td colspan="2">Cesium 137 (30 yr.)</td><td colspan="2">Cesium 137 (30 yr.)</td><td>NA</td></tr>
<tr><td>Detector</td><td colspan="2">High Efficiency
(solid phase)</td><td colspan="2">Low detection efficiency
(gas phase)</td><td>Electromagnet technology</td></tr>
<tr><td>Source Activity</td><td colspan="2">0.30 GBq (8 mCi)
± 10%Cs-137
encapsulated,
properly shielded</td><td colspan="2">~3.7 MBq (0.1 mCi)
Low gamma-ray source</td><td>NA</td></tr>
<tr><td>Neutron Source</td><td colspan="2">1.48 GBq
(40 mCi) ±10% Am-241: Be</td><td colspan="2">NA</td><td>NA</td></tr>
<tr><td>Source Lifespan</td><td colspan="2">30+ years</td><td colspan="2">8 - 10 years
(Estimated $800 replacement cost)</td><td>NA</td></tr>
<tr><td>Analysis</td><td colspan="2">Spectrometric</td><td colspan="2">Counting</td><td>NA</td></tr>
<tr><td>Device Life</td><td colspan="2">30+ years
(LTRC)</td><td colspan="2">8 to 10 years
(DEP, et.al. 2016)</td><td>NA</td></tr>
<tr><th colspan="6">Monitoring & Paperwork</th></tr>
<tr><td></td><td>Apply</td><td>Cost</td><td>Apply</td><td>Cost</td><td></td></tr>
<tr><td>Badges</td><td>Yes</td><td>$7,860/year</td><td>No</td><td>$0</td><td>NA</td></tr>
<tr><td>Leak Testing</td><td>Yes</td><td>$0, time</td><td>No</td><td>$0</td><td>NA</td></tr>
<tr><td>License Certification</td><td>Yes</td><td>~$1108/year</td><td>No</td><td>$0</td><td>NA</td></tr>
<tr><td>Paperwork Regulator Burden</td><td colspan="2">High</td><td colspan="2">Very Low</td><td>Included with LNDG</td></tr>
<tr><td>Initial Cost</td><td colspan="2">Sunken cost
($2500 trade-in value)</td><td colspan="3">$15,000 for both the 4590 and 6760
($21,000 for above and NNDG-1)</td></tr>
<tr><td>Disposal Cost</td><td colspan="2">$750</td><td colspan="2">NA</td><td>NA</td></tr>
</table>

Nuclear devices utilize a radioactive source that decays over time. The gamma ray source, Cesium-137, is the same for both the LNDG and the NDG. Cesium-137 has a 30-year half-life, however the mass of the two devices is different. This is good for some purposes like the low-nuclear source (safety) and lower reporting requirements (headaches). However, the lower mass of the LNDG may affect its lifespan compared to the NDG. The Troxler report indicates that the LNDG would need a gamma-ray source replacement after roughly 8 to 10 years, which has an estimate quote of $800. In contrast, the NDG that LTRC operates was purchased/created in 1987 (30+ years old), and has only required normal battery replacement for the display and internal computer *[12]*.

Badge and licensing costs are more for the NDG, but source replacement would be required more often with the LNDG, as the device life is roughly about three times less than the NDG. At some point, if implemented, an existing set of new LNDGs would need to be replaced every 8 to 10 years vs. 30+ years for the NDG. Not to mention the high initial cost of $15,000 per device times 107 devices would be over 1.6 million, assuming all devices across the state are replaced.

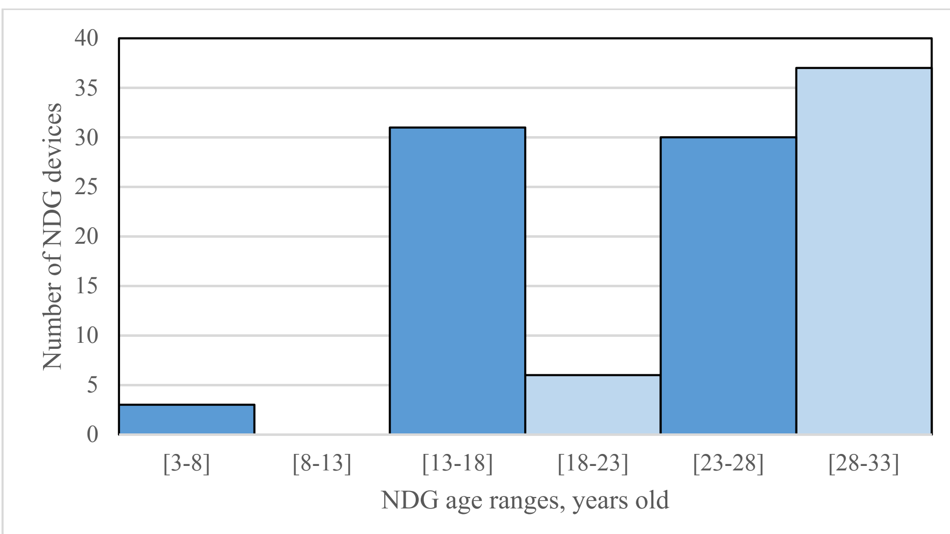

Figure 11
DOTD NDG age

Nuclear Gauge Monitoring and Safety

When dealing with radioactive material, for health and safety reasons, it is crucial to monitor the amount people are exposed to when working with these radioactive resources. A comparison of safety and training information, by device, is included below in Table 6. A hypothetical example of exposure is included below. These radiation dosage estimates are based on 3-ft. exposure rates with no holidays or leave in the calculation.

Example:

- NDG 40hrs/week x 52 weeks/year x 0.3 mrems/hour = 624 mrems/year
- LNDG 40hrs/week x 52 weeks/year x 0.01 mrems/hour = 21 mrems/year

A comparison can be made between device radiation dosage (See Table 6) and the allowable limits per the code of federal regulations [Code of Federal Regulations (CFR)] safety limits shown in Table 7. All device values are low and conservative compared to the 5,000-mrem limit. [To further this point, the DOTD senior nuclear gauge tech, responsible for managing the devices for the Department, reinforced the safe nature of the devices by stating the following example, "With nearly 16 years of all day, nearly every day gauge use, my lifetime exposure report (from monitoring badges) shows 738 mrem. A person is allowed 5,000-mrem per year."]

Table 6
Device comparison – safety and training

Safety & Training			
Parameter/Device	**NDG**	**LNDG**	**Moisture Probe**
Safety	Safe when used properly	Safer due to smaller source	NA
Radiation Dose (annual person limit: 5,000 mrems)	Higher doses 0.3 mrems/hr at 3 ft.	Smaller doses 0.01 mrems/hr at 3 ft.	NA
Security	Higher Activity Source, Reportable Radioactive source.	Lower Activity Source, non-reportable	No risk, but stored with LNDG
Storage & Shipping	Locked during transport and storage Must be in Type A Packaging	Normal equipment Type A packaging not required for shipping.	No risk, but stored with LNDG
Training (radioactive)	Extensive – Required by the US Government	Limited – Not Required by the US Government	NA
Training (existing employees)	Current DOTD familiarity	Training Required New, Similar to NDG, but different	Training Required Separate device, Bluetooth/cable

Table 7
Annual radiation exposure limits (mrem)

Whole body, blood forming organs, gonads	5,000
Lens of Eye	15,000
Extremities and Skin	50,000
Fetal (Gestation period)	500
General Public	100

Based on the US NRC Regulations, Title 10, Part 20, Code of Federal Regulations and adopted by many states. Certain state and other regulatory agencies may adhere to different limits.

Thermoluminescent badges are currently used by DOTD to detect the amount of radioactivity a person's exposure amounts. Landauer, Inc., provides radiation badges for radiation monitoring using dosimeter technology to DOTD. The NDG requires an approximate annual cost of $7,860 to Landauer, Inc., for badge usage testing and reporting. In contrast, the LNDG along with its moisture probe (which syncs with the LNDG) does not require badges because the amount of radioactivity is so small, it is below reportable limits.

Leak testing is required for all NDG and is conducted at least twice per year. This leak test determines the integrity of the NDG and whether or not it should be removed from service or repaired. In order to do this, researchers must send off a sample swabbed from the machine and wait for the results to be analyzed. While this does not directly cost researchers money, it forces an employee to focus time on extracting these samples when he or she could be working on more pressing projects. The LNDG density gauge along with the moisture probe does not require any leak testing or the time for the leak testing.

Due to the amount of radioactivity in the NDG, owners are required to have a license in order to track radioactive use. Although the NDG is relatively safe when operated correctly, it still produces radiation levels that require licensing. This license must be renewed every year; and costs about $1,108 every time it is extended. In contrast, the LNDG emits such low levels of radiation, the LNDG (and its moisture probe) do not require any licensing.

As with any operating system, there is always paperwork to ensure proper use of machinery and accurate documentation of test results. The nuclear moisture-density gauge requires data collection, a license, dosimeter badges, operator training classes, and storage and transport documentation. All of this involves tedious paperwork that is important but takes time away from employees with other projects that need to be completed. The combination of the LNDG and moisture probe only requires paperwork involved in data collection.

Regarding storage and transportation of the devices, the NDG requires double lock security at all times when in storage or transport. Even though there is a limited amount of radioactivity, ensuring the security of the NDG is essential.

The NDG has been used for years providing familiarity and ease of application on the field. However, training classes can be very costly. Table 8 shows an estimate of training class costs from recent Troxler invoices per class. Each training class (maximum of 25 students) takes time from a technician's daily activities. To better exemplify, LTRC was charged a total of $24,450 for 18 classes (312 students) in the 2016-2017 year, including 9 full-day courses for Nuclear Gauge Operator Training, One Radiation Safety Officer Training course, and 8 half-day courses for Hazardous Material Refresher Training. However, LTRC was only charged $5,225 for two full-day courses and one half-day course for only 77 students in the 2017-2018 fiscal year, since it is duly noted training for each employee is on a 3-year cycle.

Table 8
NDG training cost per class

Nuclear Gauge Operator / Radiation Safety Training	$ 1,625
Radiation Safety Officer Training	$ 2,025
Hazardous Material Refresher Training	$ 975
Note: These cost are for the 2015-2016 fiscal year and represent per class with a limit of 1 - 25 students.	

Table 9 shows a comparison of the device utilization. The LNDG the standard consists of two separate two minute counts. The first count occurs with the handle in safe position. During the second count, the handle is set in the background position and the source rod protrudes about 1.5 in. into the prepared hole. The Count Time defines how long the gauge measures. Longer count times produce better measurement precision. Troxler recommends a count time of two minutes for most sample measurements. Shorter count times may not be as accurate, but it can be set count time at less than two minutes. LNDG count time choices are 15 seconds, one minute, two minutes, and four minutes.

Table 9
Device comparison - utilization

Utilization			
Parameter/Device	**NDG**	**LNDG**	**Moisture Probe**
DOTD Specification	Current/Existing DOTD TR-401	Would need to develop or modify TR-401, etc.	Would need to modify TR-401, etc.
Sensitivity to other radioactive sources	Low (background radiation is negligible)	High – smaller source sensitive receiver (requires more background counts)	NA
Technically Accurate & Precision	Yes, meets industry standard (per Troxler)	Yes, meets industry standard (per Troxler)	Yes, meets industry standard (per Troxler)
Self-Test time	5 min (once/day)	2 sec (once/day)	NA
Warm-up time	NA	5 min (once/day)	NA
Standard Count time	4 min (once/day)	4 min (2 @ 2 min) (once/day)	NA
Test time	1 min	2 min	< 30 sec
Ease of Use	DOTD Familiar, one unit for moisture and density	New, Similar to NDG, but different. Separate moisture probe	Bluetooth, Separate hole, additional steps

DOTD TR-401 requires three measurements (moisture and density) in one hole with the NDG pivoting 120 degrees for three separate (moisture and density) measurements. The LNDG utilizes a separate moisture device, which differs from the existing DOTD standard. During our testing, this added additional steps to the DOTD process. The LNDG moisture probe requires a separate hole for moisture, which adds field time and energy to make that hole. Three measurements would/could require three holes, for a total of four holes, in contrast to the single hole required for the NDG. The diameter of the moisture probe is also larger and would damage a single hole if removed and reinserted. The probe needs good soil contact to produce accurate moisture measurements.

Asphalt Results

Site Data and Linear Regression Analysis

A total of 190 cores were acquired from asphalt paving sites by the LTRC asphalt group and contractors to compare with the NDG, TLNDG, and NNDGs. Table 10 displays the average percent density obtained by each test method, standard deviation, and percent density differences between each gauge to its corresponding core. From the table, the NNDG-1 had the highest standard deviation and the largest difference from the core, while the TLNDG and NNDG-2 were closer to the cores. Aside from the cores, TLNDG displayed the lowest standard deviation (most uniform) followed closely by NNDG-2. However, this does not indicate that a device is better than the other. An offset value should be developed and implemented to match to the cores for a given mixture. Offsets were applied to the density data using the AASHTO T-343 recommended method of calibration. Five cores and five density gauge readings were averaged and the differences (offsets) were calculated. The offsets were then applied to the remaining density points for each project. The complete data set of density results can be found in Appendix B.

Table 10
Asphalt density gauges comparison

	NDG	*TLNDG*	*NNDG-1*	*NNDG-2*	*Core*
Number of density readings obtained vs. core	30	133	124	70	-
Avg.	90.6%	93.1%	87.2%	95.0%	94.2%
Std. Dev.	3.24%	2.79%	4.38%	2.81%	1.58%
Difference from Core	3.58%	1.04%	6.93%	-0.90%	0.00%

For initial density gauge and core comparisons, linear regression methods were applied to each project as seen in Table 11. Density gauges and core densities were directly compared using the coefficient of determination (R^2). High values of R^2 would indicate that the density is highly correlated. From the observations of Table 11, the TLNDG observed four sites with fair to good results with R^2 values ranging greater than 0.6. NNDG-1 had similar results for seven sites and NNDG-2 saw 6 sites with similar results. However, TLNDG observed three sites with poor results with R^2 values ranging between less than 0.6. NNDG-1 and NNDG observed four and three sites with similar results.

Table 11
Coefficient of determination (R^2) for each project (unit weight)

Project ID	G_{mm}	*NDG*	*TLNDG*	*NNDG-1*	*NNDG-2*
ThibBC	2.489	0.9766	-	0.8879	0.7471
US90WC	2.463	0.6316	-	0.9239	0.8771
I20BC1	2.493	0.0852	-	0.3195	0.4136
US90SMA	2.397	-	-	0.3907	0.7266
I12BC	2.505	-	0.3867	0.6261	0.6002
LA98BC	2.474	-	0.8403	0.9071	0.8905
US190BC1	2.464	-	0.6118	0.6746	0.5430
US190BC2	2.450	-	0.7688	0.8112	0.6983
US190WC	2.448	-	0.9640	0.6174	0.2262
I20BC2	2.483	-	0.3802	0.0239	-
LA485BC	2.482	-	0.0020	0.0295	-

Figure 12 through 15 display the collected density data for all LTRC and contractor projects. Figure 12 and Figure 13 show the projects without offset, while Figure 14 and Figure 15 show the density results with offset. It was observed that density readings from the NDG and NNDGs were poorly correlated with core density measurements when the data for all projects were pooled with no offset. TLNDG showed fair results with R^2 value of 0.6031. However, when offsets were calculated, a significant improvement in accuracy was observed. From Figures 14 and 15, NNDG and TLNDG showed fair to good coefficients of determination when an offset was inputted with R^2 values greater than 0.65. NNDG-2 displayed the best correlation with R^2 values of 0.7376 versus 0.686 and 0.6551 of the TLNDG and NNDG-1 respectively. NDG showed poor correlation of 0.2829, but that was expected due to the device measuring deeper layers below the asphalt mat.

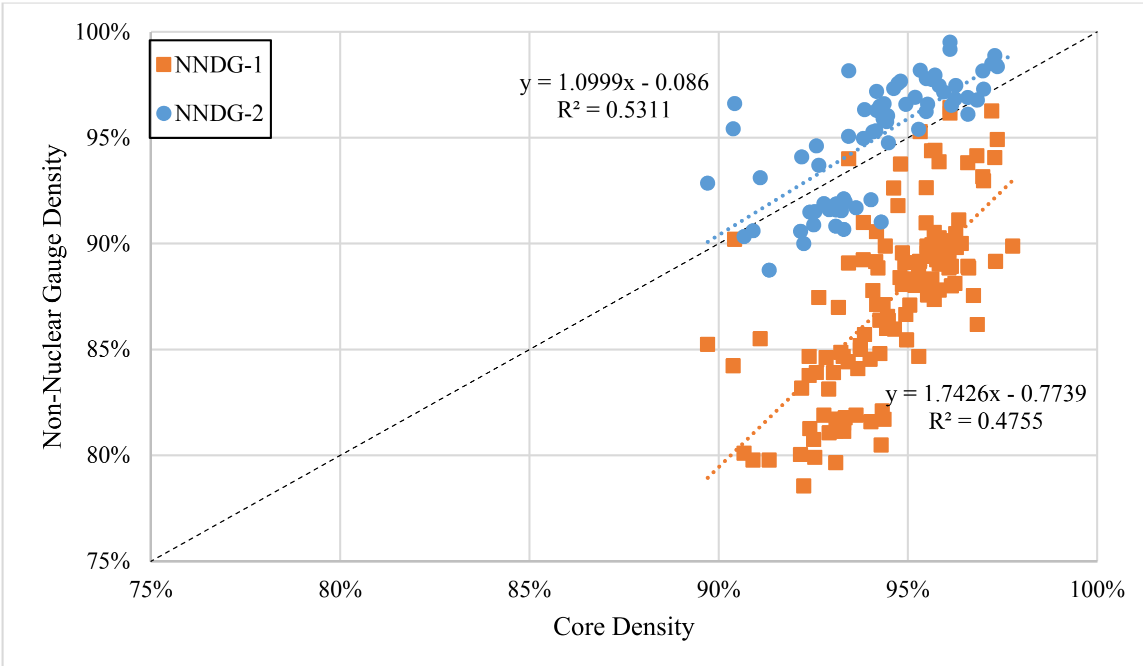

Figure 12
All projects: core vs. non-nuclear gauge (no offset)

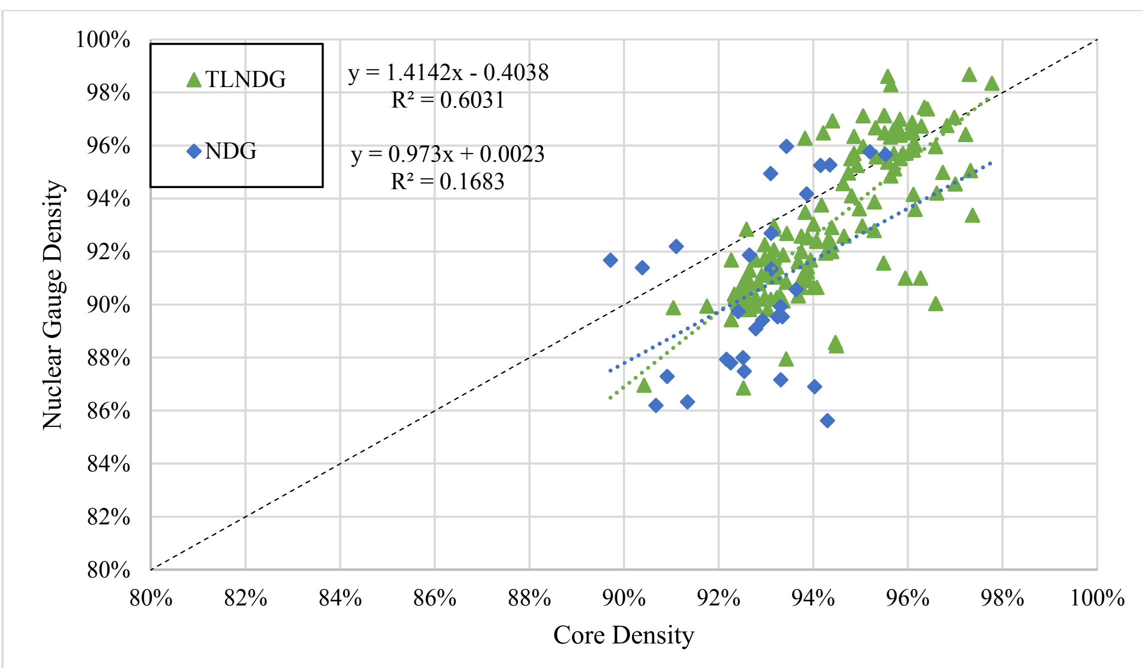

Figure 13
All projects: core vs. nuclear density gauges (no offset)

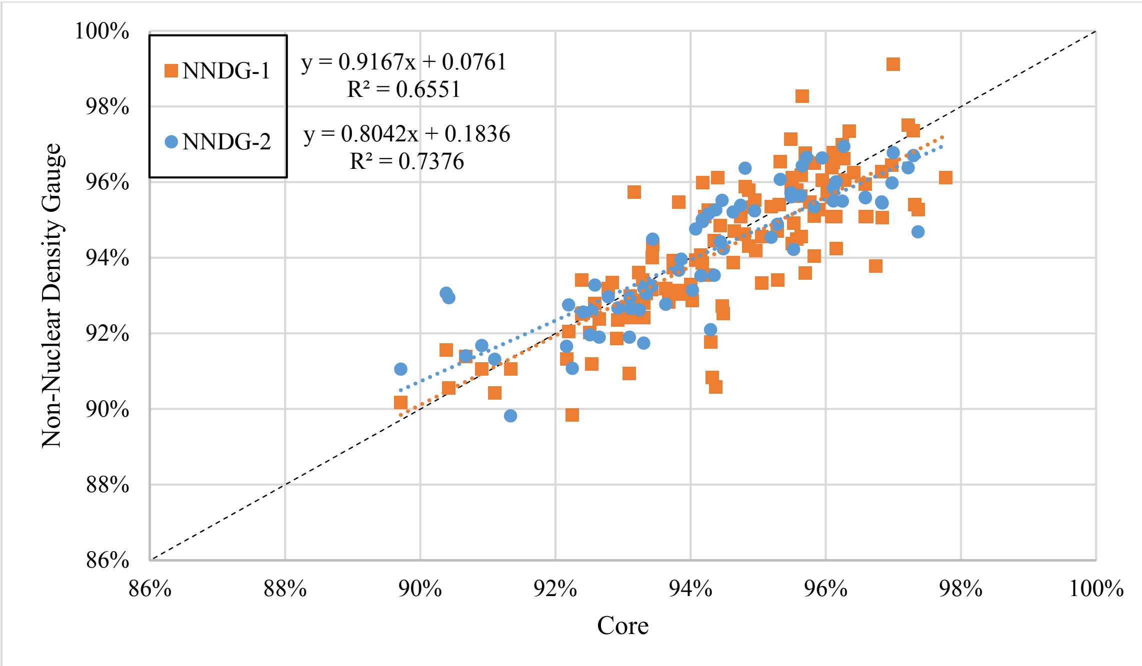

Figure 14
All projects: core vs. non-nuclear gauge (w/offset)

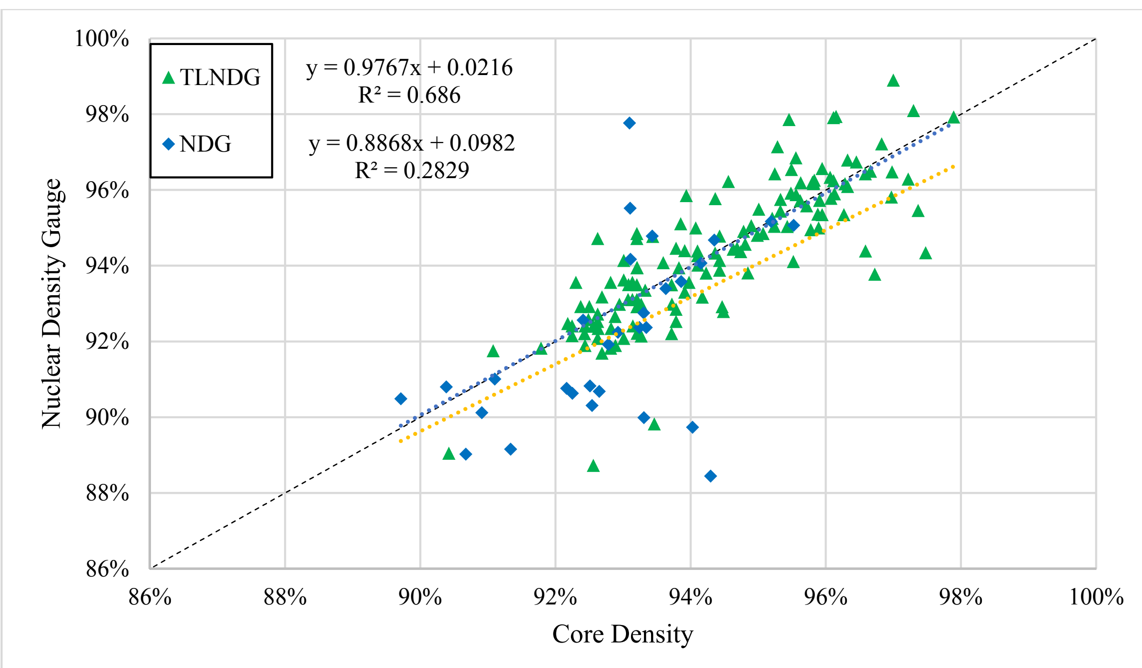

Figure 15
All projects: core vs. nuclear density gauges (w/offset)

Analysis of Variance (ANOVA)
All LTRC and contractor data were further analyzed by applying analysis of variance (ANOVA) calculations performed by the Statistical Analysis System (SAS) software. ANOVA provides a statistical test of whether the means of several groups are equal. ANOVA is useful for comparing (testing) three or more means (groups or variables) for statistical significance *[13]*.

The data entered into the software included the unit weight density, percent compaction density, temperature of asphalt mat during readings and sand patch results. Both original densities and offset densities were entered into the software. The data was organized into 11 projects labeled by location and layer type for example, “I12BC” stands for location at I-12 and the layer examined was the binder course. Spot meant one single reading was taken at the location, while NNDG-1 was where a 5-point average reading was taken.

ANOVA calculations utilized Duncan’s multiple range test to determine if the density gauges and cores were not statistically different as seen in Table 12. If a device and core have the same letter, then the density results were not statistically different from each other. From the table, the importance of an offset can be observed as very few gauges matched core results when no offset was applied. However, with offset applied, there was less statistical difference between the density gauges and the cores.

Table 12
Duncan's Multiple Range Test

NO OFFSET					WITH OFFSET				
I12BC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.96229	10	NNDG-2	A		0.95707	10	NNDG-2
A		0.95577	10	Core	A		0.95577	10	Core
B		0.91243	10	TLNDG	A		0.95574	10	TLNDG
C		0.8916	10	NNDG-1	A		0.9531	10	NNDG-1
I20BC1									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.92786	20	Core		A	0.92786	20	Core
B		0.9089	20	NNDG-2	B	A	0.92095	20	NNDG-2
C		0.88859	20	NDG	B	A	0.92026	20	NNDG-1
D		0.80755	20	NNDG-1	B		0.91739	20	NDG
I20BC2									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.93388	84	Core	A		0.95978	22	NNDG-1
B		0.91071	73	TLNDG	A		0.95571	77	spot
C		0.83776	22	NNDG-1	B		0.94675	73	TLNDG
D		0.80914	77	spot	C		0.93388	84	Core
LA485BC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.96382	37	TLNDG	A		0.95867	37	NNDG-1
B		0.95764	37	Core	A		0.95764	37	Core
C		0.89073	37	NNDG-1	B		0.95297	37	spot
D		0.87945	37	spot	B		0.95288	37	TLNDG
LA98BC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
	A	0.97964	5	NNDG-2	A		0.95738	5	NNDG-1
B	A	0.96378	5	TLNDG	A		0.95738	5	TLNDG
B		0.95736	5	Core	A		0.95738	5	NNDG-2
	C	0.9248	5	NNDG-1	A		0.95736	5	Core
ThibBC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
	A	0.9622	5	NNDG-2	A		0.93864	5	NDG
B	A	0.9444	5	NDG	A		0.93862	5	Core
B		0.93862	5	Core	A		0.93862	5	NNDG-1
	C	0.86502	5	NNDG-1	A		0.9386	5	NNDG-2

NO OFFSET					WITH OFFSET				
US90SMA									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.96158	10	NNDG-2	A		0.91171	10	NNDG-2
B		0.90892	10	Core	A		0.9106	10	NNDG-1
C		0.8565	10	NNDG-1	A		0.90892	10	Core
US90WC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.94	5	NNDG-2	A		0.9221	5	NNDG-2
A		0.9342	5	NDG	A		0.9221	5	NDG
A		0.92208	5	Core	A		0.92208	5	Core
B		0.8723	5	NNDG-1	A		0.92208	5	NNDG-1
US190WC									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.97128	5	NNDG-2	A		0.95556	5	NNDG-2
B		0.95552	5	Core	A		0.95556	5	TLNDG
C		0.934	5	TLNDG	A		0.95552	5	Core
C		0.9318	5	NNDG-1	A		0.95552	5	NNDG-1
US190BC1									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.98041	5	NNDG-2	A		0.9573	5	NNDG-2
B		0.9584	5	TLNDG	A		0.95728	5	TLNDG
B		0.95728	5	Core	A		0.95728	5	Core
B		0.94707	5	NNDG-1	A		0.95726	5	NNDG-1
US190BC2									
Duncan Grouping		Mean	N	App	Duncan Grouping		Mean	N	App
A		0.94	5	NNDG-2	A		0.94692	5	NNDG-1
A		0.9469	5	Core	A		0.94692	5	TLNDG
B		0.9342	5	NNDG-1	A		0.9469	5	Core
C		0.92208	5	TLNDG	A		0.9469	5	NNDG-2

The results of the Duncan grouping are summarized in Table 13 for the offset data only. Each density gauge was labeled either “1” for the density gauge results being not statistically different to the core or “0” for the density gauge results being statistically different core. The percentage of projects with no statistical difference between the gauge and core measurement was calculated to identify how often each density gauge matched the core results. NNDG-1 and NNDG-2 had the most success with 91 and 100 percent of projects, respectively matching with the core densities. The NDG and TLNDG results matched core densities for

67 and 71 percent of projects, respectively. The single reading (spot) did not match cores for any project as a single reading can lead to high variability.

Table 13
Percentage of projects with no difference from core

Project	NDG	TLNDG	NNDG-1	spot	NNDG-2
I12BC	x	1	1	x	1
I20BC1	0	x	1	x	1
I20BC2	x	0	0	0	x
LA485BC	x	0	1	0	x
LA98BC	x	1	1	x	1
ThibBC	1	x	1	x	1
US190WC	x	1	1	x	1
US190BC1	x	1	1	x	1
US190BC2	x	1	1	x	1
US90WC	1	x	1	x	1
US90SMA	x	x	1	x	1
Total	2/3	5/7	10/11	0/2	9/9
Percentage of projects with no difference from core	**67%**	**71%**	**91%**	**0%**	**100%**

Offset Variability

Variability within the offsets was a cause of concern by members of the PRC committee. High variability may cause density reading inaccuracies for the rest of the spots tested. Each density gauge was offset by averaging the unit weight of the first five cores as per manufacturer and AASHTO recommendations. To examine variability, the standard deviation of the offsets was examined. Table 14 displays the standard deviations of the five core offsets for each project. The five individual offsets from each project displayed less than one percent variation, which is a reasonable variation to not adversely affect the rest of the density readings.

Table 14
Standard deviation of individual offsets per project

Mix ID	NDG	TLNDG	NNDG-1	NNDG-2
	standard deviation of the offsets			
ThibBC	0.34%		0.70%	1.41%
US90WC	1.12%		0.46%	0.75%
I20BC1	1.51%		0.50%	0.42%
US90SMA			0.98%	0.90%
I12BC		1.60%	1.27%	0.63%
LA98BC		0.79%	0.37%	0.71%
US190BC1		0.55%	1.37%	0.97%
US190BC2		1.45%	1.08%	1.74%
US190WC		0.23%	0.78%	1.11%
I20BC2		1.20%	1.47%	
LA485BC		0.62%	0.68%	
Average St. Dev.	**0.99%**	**0.92%**	**0.88%**	**0.96%**
Range	**0.34%-1.51%**	**0.23%-1.60%**	**0.37%-1.47%**	**0.42%-1.74%**

Surface Texture Analysis
Additional comparisons were conducted to see if the effect of surface texture on the gauge readings were significant. The hypothesis of this comparison is surface texture has an effect on density gauges if a large surface area existed due to higher air voids on the surface of the mix would influence the readings of the gauges to give a lower density value. A sand patch test was performed to determine the average macrotexture depth of a pavement surface. It uses a volumetric approach of measuring pavement macrotexture. In this study, a known volume of fine sand is spread evenly over the pavement surface to form a circle, thus filling the surface voids with fine sand. The diameter of the circle is measured on four axes and the value averaged. This value is then used to calculate the mean texture depth (MTD). In order to determine if the surface texture of the pavement has an effect on the density readings of the gauges, the MTD was correlated with the average density difference (offset) between the gauges and core.

Table 15 lists the MTD (mm) and offsets (lbs./ft^3) between each gauge from the core. As seen from the table, sand patch testing was performed on the last six projects as the decision to add sand patch testing was made at the midpoint of the research. The results from each project were plotted in Figure 16.

From the figure, a trend was observed as the surface texture of the pavement trended to more air voids, the offset resulted in larger values for the TLNDG and NNDG-1. However, NNDG-2 results showed the opposite effect where the larger the surface texture, then the lower the difference. This trend for the TLNDG and NNDG-1 shows that the larger the surface texture of the pavement, then the more effect this would have on the density gauges by increasing the offset difference. The larger offset may lead to increase variability in the density results. However, NNDG-2 results did not show this trend, but instead showed the opposite.

Table 15
Sand patch results

Location	***MTD (mm)***	***TLNDG***	***NNDG-1***	***NNDG-2***	***Core***
		average difference from core (offset)			
I-12	1.15	6.80	10.06	-1.01	0
LA 98	0.74	-0.90	5.10	-3.36	0
US 190	0.78	-0.20	1.92	-3.24	0
US 190	0.90	3.19	0.54	-5.61	0
US 190	0.92	0.71	3.26	-1.98	0

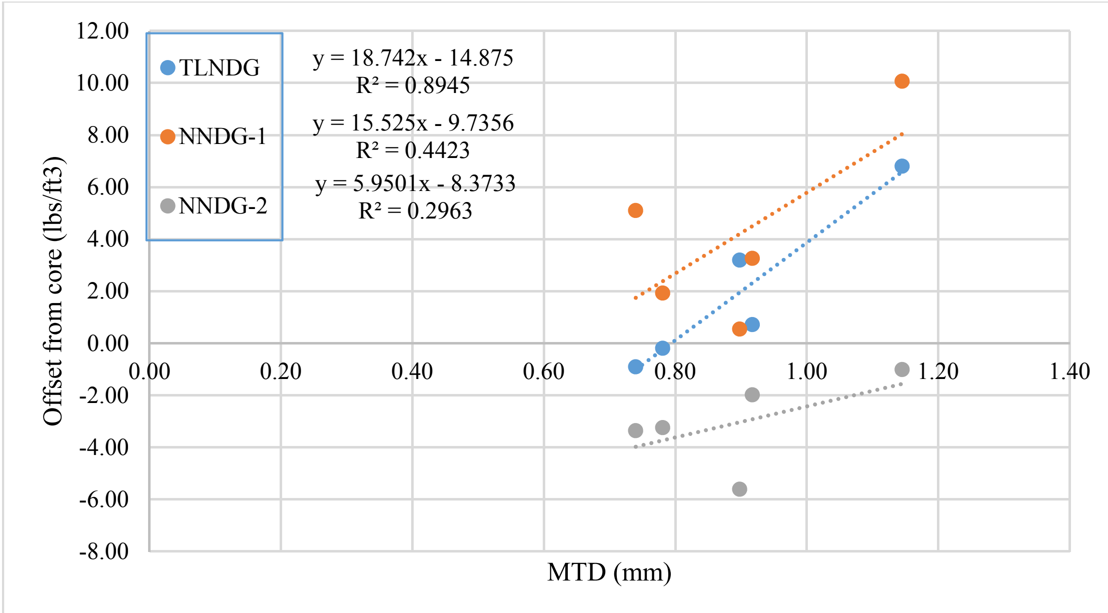

Figure 16
Surface texture and offset correlation

Cost and Time Analysis

A simple cost analysis was conducted for the coring rig, nuclear and non-nuclear density gauges which compared initial costs, training requirements, and typical maintenance costs. Table 16 displays the pricing and testing times of respective devices. The pricing for each component was for a single device and pricing for training was for a single person. Device quotes, maintenance estimates, and other miscellaneous costs originated from device manufacturers, contractors, experience, and previous literature.

Core rig expenses were added since final density acceptance requires density from cores. A typical core rig requires oil changes, diesel fuel, water, and multiple core bits over the year, which makes the costs higher for maintaining a core rig. The TLNDG and NNDG require less maintenance but do require annual calibration. TLNDG does require extensive safety training which makes it costlier over time versus the NNDG. The costs for each device after 5-years was calculated to be $25,000 for a core rig, $13,099 for a TLNDG, and $10,700 for a NNDG.

These costs coincide to previous literature which show the NNDG to be more economical than the NDG. Researchers at the University of Nebraska conducted a life cycle cost analysis of both density gauges and calculated the net present value of the NDG to be $27,234.10 versus $12,003.04 for a NNDG *[6]*. Researchers at Iowa State saw similar savings. They estimated 5-year savings of $50,318 from using a NNDG versus a NDG *[4]*.

Device operation and testing times were carefully observed during field testing. NNDGs were experienced to be easier to handle and operate than the TLNDG. NNDG required only turning on the gauges in their respective cases against having to take several standard counts with the TLNDG. Additionally, NNDG single readings take roughly 5 seconds versus the 1-minute readings from the TLNDG. Testing time from setup, including inputting project info such as mix type, depth of measurements, and G_{mm}, to reaching a density reading took roughly 15 minutes for the TLNDG and 5 minutes for the NNDGs. Core readings usually take hours to obtain densities as they require lab testing.

Table 16
Cost comparisons between density devices

Density Gauge Cost			
	Core Rig	**Thin Lift Nuclear Gauge**	**Non-Nuclear Gauge**
Initial/One Time Costs			
Equipment	$15,000	$9,850	$8,200
RSO training (per person)	$0	$290	$0
Radiation safety & Certification Class (per person)	$0	$129	$0
Annual Costs			
Maintenance (oil change or calibration)	$500	$500	$500
Core drill bits	$1,000	$0	$0
Fuel costs	$500	$0	$0
Nuclear gauge refresher course (per person)	$0	$49	$0
HAZMAT certification ($49 every 3 years per person)	$0	$17	$0
Cost after 5 years			
Cost after 5 years (1 device and 1 person)	$25,000	$13,099	$10,700
Testing Times			
Time from setup to density reading	24 hours	15 minutes	5 minutes

CONCLUSIONS

The objective of this research study was to evaluate low to non-nuclear testing devices that could perform the same functions as the NDG and reduce coring for asphalt paving. The following conclusions were listed below for both geotechnical and asphalt sections:

Geotechnical

- The LNDG was found to capture the dry density relatively well compare to the NDG with a returned R^2 value of 0.84. The LNDG moisture content results were slightly wetter with an R^2 value of 0.67 when compared to the NDG.
- The LNDG maximum depth capability does not meet the current DOTD TR-401 depth requirements for base course and embankment depth quality assurance tests. This would create a problem within the department with 12-in. thick layers.
- The LNDG requires a longer test time than the NDG. The time is double that of the NDG, and would therefore double test time and field time for technicians.
- The LNDG has a smaller radioactive source that is sensitive to other radioactive devices and is even affected by naturally occurring radiation.
- The LNDG has a separate moisture probe with a diameter larger than the LNDG probe. The moisture probe would require its own adjacent hole if consecutive measurements in the same hole are required per the requirements of TR-401. This would create more effort and time for technicians in the field.
- The LNDG's smaller source needs replacing on an 8 to 10-year cycle, which would create maintenance costs, labor, and paperwork for the Department. These costs can be difficult to quantify, but replacement of the device roughly three times more than existing devices, would be cumbersome and would add annual costs to the department, since the NDG can last over three times as long.
- The NDG is safe when utilized properly with normal exposure rates well below the annual allowable limit of 5,000 mrems.
- NDG safety training costs were from \$9,500 to roughly \$25,000 a year per 3-year training cycle. While the LNDG wouldn't require nuclear safety training classes, it would require transitional training classes, if implemented.
- Both devices require time, effort, training, and consideration. The NDG is a known quantity and is well established within DOTD.

Asphalt

- Linear regression analysis was utilized to correlate density gauges to cores. The results of the NNDG and TLNDG showed fair to good correlation to roadway cores, NDG showed fair to poor correlation to roadway cores.
- ANOVA statistical analysis was conducted on the density data for further statistical evaluation. It was found without offset calibration, both NDG and NNDG results differed from reported core densities with statistical significance. However, when applying an offset to density gauges as recommended by AASHTO and the gauge manufacturers, hypothesis testing showed that the both NNDG results were not significantly different. Furthermore, as indicated by the greater P-value for NNDG results than for NDG results, calibrated NNDG results agreed better with core results than did nuclear gauge results.
- Sand patch results were mixed as the TLNDG and NNDG-1 showed promising results that agreed with the hypothesis of surface texture effect on gauge readings, but NNDG-2 data showed opposite results. A strong conclusion could not be made regarding surface texture effects on the density gauges.
- Device usage and practicality were observed when taking readings. Both NNDGs were, as described by each manufacturer, very easy to operate. NDG and TLNDG testing time was typically 10 to 15 minutes from gauge setup and calibration to density results. The NNDG typically only needed 5 minutes from gauge setup to density results.
- Cost comparisons of each density measuring tool (core rig, NDG, and NNDG) exhibited that NNDGs would provide the most cost savings. Core rig and NDG cost entail higher maintenance and training costs versus the NNDGs.

RECOMMENDATIONS

Based on the results from this study, the following recommendations are made for geotechnical and asphalt QA procedures:

Geotechnical

Based on the results of the geotechnical research, the authors recommend retaining the NDG for soils density for both QC and QA testing due to limitations of the LNDG. The authors recommend further testing of the LNDG once the technology improves, essentially in the depth of the probe.

Asphalt

Based on the results of the asphalt research, the authors recommend the use of the non-destructive testing for both QC and QA testing provided the manufacturer's and AASHTO T-343 recommendation to calibrate the device daily by applying a core-calibration offset is followed. The authors do not recommend the use of either gauge for QA testing without conducting the recommended calibration.

A pilot program is recommended to evaluate the logistical application of using non-destructive density determination for acceptance testing.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ALF	Accelerated Loading Facility device
ASTM	American Society for Testing and Materials
avg.	average
cm	centimeter(s)
DOTD	Louisiana Department of Transportation and Development
FHWA	Federal Highway Administration
G_{mm}	maximum theoretical density
ft.	foot (feet)
HMA	hot mix asphalt
in.	inch(es)
lb.	pound(s)
LTRC	Louisiana Transportation Research Center
m	meter(s)
mm	millimeters
mrem	millirem(s) – measurement of radiation
LNDG	low-nuclear density gauge
MTD	mean texture depth
NDG	nuclear density gauge
NDT	non-destructive testing
NMAS	nominal maximum aggregate size
NNDG	non-nuclear density gauge
PRF	Pavement Research Facility
QA	quality assurance
QAM	Louisiana's Quality Assurance Manual
QC	quality control
R-Value	coefficient of correlation
S.D.	standard deviation
TLNDG	thin-lift nuclear density gauge

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APPENDIX A

Geotechnical

Table 17
Nuclear and LNDG readings for PRF section A

Nuclear Reading						LNDG Reading				
1	2	3	S.D.	Avg.	**Area A**	Avg.	S.D.	1	2	3
99.8	100.5	100.8	***0.5***	***100.4***	Wet Density, pcf	***101.7***	***0.3***	101.4	101.9	101.8
75.8	76.0	77.9	***1.2***	***76.6***	Dry Density, pcf	***76.4***	***0.1***	76.3	76.5	76.4
31.0	32.2	29.5	***1.4***	***30.9***	Moisture, %	***33.1***	***0.2***	32.9	33.3	33.2
24.1	24.5	22.9	***0.8***	***23.8***	Moisture by Mass, %	***25.4***	***0.2***	25.1	25.5	25.5
1	2	3	S.D.	Avg.	**Area B**	Avg.	S.D.	1	2	3
101.7	101.8	100.2	***0.9***	***101.2***	Wet Density, pcf	***100.9***	***0.3***	101.3	100.7	100.7
76.8	77.8	75.9	***1.0***	***76.8***	Dry Density, pcf	***68.2***	***0.3***	68.6	68.0	68.0
32.4	30.9	31.9	***0.8***	***31.7***	Moisture, %	***48.0***	***0.3***	47.6	48.2	48.1
24.9	24.1	24.2	***0.4***	***24.4***	Moisture by Mass, %	***32.7***	***0.0***	32.7	32.7	32.7
1	2	3	S.D.	Avg.	**Area C**	Avg.	S.D.	1	2	3
99.8	94.3	98.1	***2.8***	***97.4***	Wet Density, pcf	***104.1***	***2.9***	100.8	104.9	106.5
75.2	74.9	75.1	***0.2***	***75.1***	Dry Density, pcf	***75.9***	***3.2***	72.3	77.5	78.0
32.8	32.6	30.6	***1.2***	***32.0***	Moisture, %	***37.5***	***1.6***	39.4	36.5	36.6
24.7	24.4	22.9	***1.0***	***24.0***	Moisture by Mass, %	***28.5***	***0.1***	28.5	28.4	28.5
1	2	3	S.D.	Avg.	**Area D**	Avg.	S.D.	1	2	3
102.4	99.3	100.2	***1.6***	***100.6***	Wet Density, pcf	***101.8***	***0.2***	102.0	101.8	101.7
79.7	76.6	78.2	***1.6***	***78.2***	Dry Density, pcf	***74.4***	***0.2***	74.6	74.3	74.2
28.5	29.6	28.2	***0.7***	***28.8***	Moisture, %	***36.9***	***0.1***	36.8	36.9	37.0
22.7	22.7	22.1	***0.3***	***22.5***	Moisture by Mass, %	***27.5***	***0.1***	27.4	27.5	27.5

Table 18
Nuclear and LNDG readings for PRF section B

Nuclear Reading						LNDG Reading				
1	**2**	**3**	**S.D.**	**Avg.**	Area A	**Avg.**	**S.D.**	**1**	**2**	**3**
106.3	**107.1**	**108.9**	*1.3*	*107.4*	**Wet Density, pcf**	*109.4*	*2.0*	**111.7**	**108.2**	**108.4**
83.9	**83.3**	**84.9**	*0.8*	*84.0*	**Dry Density, pcf**	*92.0*	*1.7*	**93.9**	**90.5**	**91.7**
26.7	**28.6**	**28.7**	*1.1*	*28.0*	**Moisture, %**	*18.9*	*0.7*	**19.0**	**19.6**	**18.2**
22.4	**23.8**	**24.3**	*1.0*	*23.5*	**Moisture by Mass, %**	*17.4*	*0.6*	**17.8**	**17.8**	**16.7**
1	**2**	**3**	**S.D.**	**Avg.**	Area B	**Avg.**	**S.D.**	**1**	**2**	**3**
104.0	**99.0**	**95.9**	*4.1*	*99.6*	**Wet Density, pcf**	*114.4*	*1.1*	**113.2**	**115.2**	**114.8**
83.2	**80.3**	**77.0**	*3.1*	*80.2*	**Dry Density, pcf**	*95.8*	*0.9*	**94.8**	**96.5**	**96.2**
25.0	**23.2**	**24.5**	*0.9*	*24.2*	**Moisture, %**	*19.4*	*0.1*	**19.4**	**19.5**	**19.3**
20.8	**18.7**	**18.8**	*1.2*	*19.4*	**Moisture by Mass, %**	*18.5*	*0.3*	**18.4**	**18.8**	**18.3**
1	**2**	**3**	**S.D.**	**Avg.**	Area C	**Avg.**	**S.D.**	**1**	**2**	**3**
101.2	**100.7**	**97.5**	*2.0*	*99.8*	**Wet Density, pcf**	**N/A**				
77.2	**77.4**	**75.1**	*1.3*	*76.6*	**Dry Density, pcf**					
31.1	**30.1**	**29.8**	*0.7*	*30.3*	**Moisture, %**					
24.0	**23.3**	**22.4**	*0.8*	*23.2*	**Moisture by Mass, %**					
1	**2**	**3**	**S.D.**	**Avg.**	Area D	**Avg.**	**S.D.**	**1**	**2**	**3**
102.9	**103.5**	**101.9**	*0.8*	*102.8*	**Wet Density, pcf**	**N/A**				
79.5	**78.5**	**78.2**	*0.7*	*78.7*	**Dry Density, pcf**					
29.4	**31.9**	**30.4**	*1.3*	*30.6*	**Moisture, %**					
23.4	**25.0**	**23.7**	*0.9*	*24.0*	**Moisture by Mass, %**					

Table 19
Nuclear and LNDG readings for PRF section C

Nuclear Reading						LNDG Reading				
1	2	3	S.D.	Avg.	**Area A**	Avg.	S.D.	1	2	3
115.0	113.7	114.4	***0.7***	***114.4***	Wet Density, pcf	***120.0***	***4.5***	117.1	125.2	117.8
96.1	94.9	95.2	***0.6***	***95.4***	Dry Density, pcf	***98.3***	***4.4***	95.4	103.4	96.1
19.6	19.8	20.1	***0.3***	***19.8***	Moisture, %	***21.8***	***0.9***	22.8	21.0	21.6
18.8	18.7	19.2	***0.3***	***18.9***	Moisture by Mass, %	***21.7***	***0.1***	21.8	21.7	21.7
1	2	3	S.D.	Avg.	**Area B**	Avg.	S.D.	1	2	3
113.5	113.5	114.2	***0.4***	***113.7***	Wet Density, pcf	***112.7***	***0.6***	113.1	n/a	112.3
96.4	96.0	96.3	***0.2***	***96.2***	Dry Density, pcf	***93.0***	***0.5***	93.3	n/a	92.6
17.8	18.2	18.6	***0.4***	***18.2***	Moisture, %	***21.3***	***0.1***	21.2	n/a	21.4
17.1	17.5	17.9	***0.4***	***17.5***	Moisture by Mass, %	***19.8***	***0.0***	19.8	n/a	19.8
1	2	3	S.D.	Avg.	**Area C**	Avg.	S.D.	1	2	3
108.4	110.5	109.7	***1.1***	***109.5***	Wet Density, pcf	***117.0***	***4.2***	114.6	121.9	114.6
91.7	93.8	93.2	***1.1***	***92.9***	Dry Density, pcf	***94.2***	***4.2***	91.7	99.1	91.9
18.2	17.8	17.7	***0.3***	***17.9***	Moisture, %	***24.3***	***1.1***	25.0	23.0	24.8
16.7	16.7	16.5	***0.1***	***16.6***	Moisture by Mass, %	***22.8***	***0.1***	22.9	22.8	22.8
1	2	3	S.D.	Avg.	**Area D**	Avg.	S.D.	1	2	3
106.6	106.5	106.7	***0.1***	***106.6***	Wet Density, pcf	***116.7***	***0.2***	116.9	116.6	116.6
89.5	89.0	89.7	***0.4***	***89.4***	Dry Density, pcf	***92.0***	***0.2***	92.1	91.8	92.0
19.1	19.6	18.9	***0.4***	***19.2***	Moisture, %	***27.0***	***0.2***	27.0	27.1	26.8
17.1	17.5	16.9	***0.3***	***17.2***	Moisture by Mass, %	***24.7***	***0.1***	24.8	24.8	24.6

Table 20
Nuclear and LNDG readings LA 98 - station 266 + 00

Nuclear Reading					Friday 9/29/17	LNDG Reading				
1	2	3	S.D.	Avg.	**STA 266 (Area A)**	Avg.	S.D.	1	2	3
118.1	119.4	114.3	***2.7***	***117.3***	Wet Density, pcf	***122.1***	***0.2***	122.2	121.9	122.1
99.1	101.9	97.4	***2.3***	***99.5***	Dry Density, pcf	***105.9***	***0.3***	106.1	105.5	106.1
18.3	17.2	17.3	***0.6***	***17.6***	Moisture, %	***15.3***	***0.2***	15.2	15.5	15.1
18.2	17.5	16.9	***0.7***	***17.5***	Moisture by Mass, %	***16.2***	***0.2***	16.1	16.4	16.0
1	2	3	S.D.	Avg.	**STA 266 (Area B)**	Avg.	S.D.	1	2	3
118.3	118.9	118.4	***0.3***	***118.5***	Wet Density, pcf	***119.0***	***1.0***	117.9	119.3	119.8
100.8	100.0	100.0	***0.5***	***100.3***	Dry Density, pcf	***102.4***	***1.0***	101.3	102.6	103.2
17.3	18.9	18.4	***0.8***	***18.2***	Moisture, %	***16.2***	***0.2***	16.4	16.2	16.1
17.5	18.9	18.4	***0.7***	***18.3***	Moisture by Mass, %	***16.6***	***0.0***	16.6	16.6	16.6
1	2	3	S.D.	Avg.	**STA 266 (Area C)**	Avg.	S.D.	1	2	3
115.4	116.8	118.7	***1.7***	***117.0***	Wet Density, pcf	***115.7***	***1.1***	114.5	116.3	116.4
98.6	99.0	100.2	***0.8***	***99.3***	Dry Density, pcf	***99.3***	***1.0***	98.1	99.8	100.0
17.1	17.9	18.5	***0.7***	***17.8***	Moisture, %	***16.6***	***0.2***	16.8	16.5	16.4
16.9	17.7	18.5	***0.8***	***17.7***	Moisture by Mass, %	***16.4***	***0.0***	16.4	16.4	16.4
1	2	3	S.D.	Avg.	**STA 266 (Area D)**	Avg.	S.D.	1	2	3
119.8	117.8	119.3	***1.0***	***119.0***	Wet Density, pcf	***121.6***	***2.1***	119.3	122.3	123.3
105.8	104.2	105.3	***0.8***	***105.1***	Dry Density, pcf	***105.5***	***2.2***	103.0	106.2	107.3
13.3	13.1	13.2	***0.1***	***13.2***	Moisture, %	***15.3***	***0.5***	15.8	15.2	14.9
14.0	13.7	13.9	***0.2***	***13.9***	Moisture by Mass, %	***16.1***	***0.2***	16.3	16.1	16.0
1	2	3	S.D.	Avg.	**STA 266 (Area E)**	Avg.	S.D.	1	2	3
115.2	115.4	117.4	***1.2***	***116.0***	Wet Density, pcf	***121.9***	***1.2***	122.6	122.7	120.5
97.9	98.8	100.6	***1.4***	***99.1***	Dry Density, pcf	***104.8***	***1.6***	105.7	105.7	103.0
17.8	16.8	16.8	***0.6***	***17.1***	Moisture, %	***16.3***	***0.5***	16.0	16.0	16.9
17.4	16.6	16.9	***0.4***	***17.0***	Moisture by Mass, %	***17.1***	***0.3***	16.9	17.0	17.5

Table 21
Nuclear and LNDG readings LA 98 - station 267 + 00

Nuclear Reading					Friday 9/29/17	LNDG Reading				
1	2	3	S.D.	Avg.	**STA 267 (Area A)**	Avg.	S.D.	1	2	3
118.8	117.6	120.6	***1.5***	***119.0***	Wet Density, pcf	***127.8***	***0.9***	127.1	127.6	128.8
102.0	100.2	102.9	***1.4***	***101.7***	Dry Density, pcf	***107.5***	***1.2***	106.3	107.4	108.7
16.4	17.4	17.1	***0.5***	***17.0***	Moisture, %	***18.8***	***0.3***	19.0	18.8	18.5
16.8	17.5	17.6	***0.4***	***17.3***	Moisture by Mass, %	***20.2***	***0.1***	20.3	20.2	20.1
1	2	3	S.D.	Avg.	**STA 267 (Area B)**	Avg.	S.D.	1	2	3
120.8	120.3	119.7	***0.6***	***120.3***	Wet Density, pcf	***129.7***	***0.3***	129.9	129.9	129.3
101.8	101.3	100.5	***0.7***	***101.2***	Dry Density, pcf	***107.4***	***0.2***	107.5	107.5	107.1
18.7	18.8	19.1	***0.2***	***18.9***	Moisture, %	***20.8***	***0.0***	20.8	20.8	20.8
19.0	19.0	19.2	***0.1***	***19.1***	Moisture by Mass, %	***22.3***	***0.1***	22.4	22.3	22.2
1	2	3	S.D.	Avg.	**STA 267 (Area C)**	Avg.	S.D.	1	2	3
120.7	119.8	118.9	***0.9***	***119.8***	Wet Density, pcf	***129.2***	***0.7***	128.5	129.4	129.8
102.7	102.5	101.6	***0.6***	***102.3***	Dry Density, pcf	***107.6***	***0.8***	106.8	107.8	108.3
17.5	17.0	17.1	***0.3***	***17.2***	Moisture, %	***20.1***	***0.2***	20.3	20.0	19.9
18.0	17.4	17.4	***0.3***	***17.6***	Moisture by Mass, %	***21.6***	***0.1***	21.7	21.6	21.5
1	2	3	S.D.	Avg.	**STA 267 (Area D)**	Avg.	S.D.	1	2	3
120.9	121.7	121.2	***0.4***	***121.3***	Wet Density, pcf	***126.6***	***1.0***	125.6	126.8	127.5
106.6	106.9	106.1	***0.4***	***106.5***	Dry Density, pcf	***110.0***	***1.1***	108.9	110.2	111.0
13.4	13.8	14.3	***0.5***	***13.8***	Moisture, %	***15.1***	***0.2***	15.3	15.0	14.9
14.3	14.6	15.1	***0.4***	***14.7***	Moisture by Mass, %	***16.6***	***0.1***	16.6	16.6	16.5
1	2	3	S.D.	Avg.	**STA 267 (Area E)**	Avg.	S.D.	1	2	3
117.4	116.2	113.6	***1.9***	***115.7***	Wet Density, pcf	***116.6***	***1.1***	117.4	115.3	117.0
99.3	98.9	97.1	***1.2***	***98.4***	Dry Density, pcf	***96.5***	***2.1***	98.7	94.6	96.3
18.3	17.6	17.0	***0.7***	***17.6***	Moisture, %	***21.5***	***0.5***	21.0	21.9	21.5
18.2	17.4	16.5	***0.9***	***17.4***	Moisture by Mass, %	***20.7***	***0.0***	20.7	20.7	20.7

APPENDIX B

Asphalt

Table 22
Percent density results

Date	Point	DOTD Project #	Route	Mix ID	Station #	Gmm	NDG	TLNDG	NNDG-1	NNDG-2	Core
							Density (%Gmm) - No Offset				
3/23/2017	1	H.012291	Thibodaux	ThibBC	31880	2.489	95.66%	x	87.56%	96.58%	95.52%
	2				31780	2.489	94.18%	x	85.70%	96.32%	93.86%
	3				31669	2.489	91.40%	x	84.22%	95.42%	90.39%
	4				31554	2.489	95.77%	x	88.02%	96.90%	95.19%
	5				31431	2.489	95.27%	x	87.11%	95.89%	94.35%
4/6/2017	6	H.009658	US 90	US90WC	50300	2.463	95.26%	x	89.14%	95.32%	94.15%
	7				50400	2.463	95.97%	x	89.07%	95.06%	93.43%
	8				50500	2.463	91.68%	x	85.24%	92.85%	89.71%
	9				50600	2.463	92.20%	x	85.50%	93.11%	91.10%
	10				50700	2.463	91.87%	x	87.45%	93.69%	92.65%
6/27/2017 - 6/28/2017	11	H.010480	I-20	I20BC1	96875	2.494	91.31%	x	81.09%	91.55%	93.07%
	12				97075	2.494	89.06%	x	81.86%	91.85%	92.75%
	13				97275	2.494	86.17%	x	80.06%	90.29%	90.64%
	14				97475	2.494	92.66%	x	81.67%	91.83%	93.07%
	15				97875	2.494	89.51%	x	81.73%	91.93%	93.31%
	16				98075	2.494	90.54%	x	81.86%	91.65%	93.60%
	17				98275	2.494	89.70%	x	81.22%	91.45%	92.37%
	18				98475	2.494	89.51%	x	81.54%	91.51%	93.20%
	19				98875	2.494	87.26%	x	79.74%	90.56%	90.87%
	20				99075	2.494	89.38%	x	81.03%	91.56%	92.89%
	21				99275	2.494	86.88%	x	81.54%	92.03%	93.99%
	22				99475	2.494	87.13%	x	81.48%	92.07%	93.27%
	23				80700	2.494	87.77%	x	78.52%	89.96%	92.21%
	24				80900	2.494	89.90%	x	81.09%	90.63%	93.27%
	25				81100	2.494	87.90%	x	80.00%	90.54%	92.13%
	26				81300	2.494	87.97%	x	80.71%	90.85%	92.47%
	27				78200	2.494	86.30%	x	79.74%	88.70%	91.30%
	28				78400	2.494	87.45%	x	79.87%	86.78%	92.50%
	29				78600	2.494	85.59%	x	80.45%	90.98%	94.26%
	30				78800	2.494	94.91%	x	79.61%	90.78%	93.06%

7/26/2017	31	H.011327	US 90	US90SMA	17500	2.397	x	x	83.91%	94.61%	92.58%
	32				17550	2.397	x	x	83.17%	94.09%	92.20%
	33				17600	2.397	x	x	86.38%	96.49%	94.26%
	34				17650	2.397	x	x	88.12%	96.83%	96.25%
	35				17700	2.397	x	x	86.18%	96.78%	96.84%
	36				17750	2.397	x	x	85.98%	95.75%	94.44%
	37				17800	2.397	x	x	86.65%	96.57%	94.95%
	38				17850	2.397	x	x	87.11%	96.29%	94.18%
	39				17900	2.397	x	x	89.39%	97.76%	95.65%
	40				17950	2.397	x	x	81.70%	96.60%	94.37%
10/18/2017	41	H.010558	I-12	I12BC	25700	2.505	x	91.00%	89.88%	97.15%	95.95%
	42				25750	2.505	x	91.00%	90.46%	97.46%	96.27%
	43				25800	2.505	x	94.55%	92.96%	97.29%	97.00%
	44				25850	2.505	x	90.04%	88.92%	96.10%	96.59%
	45				25900	2.505	x	93.59%	88.92%	96.52%	96.15%
	46				25700	2.505	x	88.57%	86.56%	96.03%	94.47%
	47				25750	2.505	x	90.65%	87.77%	95.27%	94.08%
	48				25800	2.505	x	92.80%	88.54%	95.40%	95.29%
	49				25850	2.505	x	88.44%	86.37%	94.75%	94.49%
	50				25900	2.505	x	91.57%	90.97%	96.23%	95.48%
11/27/2017	51	H.012128	LA 98	LA98BC	30400	2.474	x	97.10%	93.15%	98.15%	96.98%
	52				30350	2.474	x	95.02%	91.79%	97.56%	94.74%
	53				30300	2.474	x	93.83%	90.56%	97.19%	94.17%
	54				30250	2.474	x	97.19%	92.63%	97.79%	95.49%
	55				30200	2.474	x	98.75%	94.06%	98.88%	97.30%
12/21/2017	56	H.009549	US 190	US190BC1	21600	2.464	x	94.57%	92.62%	97.31%	94.60%
	57				21700	2.464	x	96.39%	93.85%	97.45%	97.19%
	58				21800	2.464	x	96.32%	94.37%	97.75%	95.60%
	59				21900	2.464	x	95.57%	95.28%	98.18%	95.30%
	60				22000	2.464	x	96.42%	96.26%	98.49%	95.80%
12/29/2017	61			US190BC2	25400	2.450	x	95.83%	96.15%	99.51%	96.11%
	62				25500	2.450	x	92.69%	94.00%	98.16%	93.44%
	63				25610	2.450	x	86.96%	90.20%	96.61%	90.42%
	64				25700	2.450	x	94.16%	96.42%	99.17%	96.11%
	65				25800	2.450	x	93.37%	94.91%	98.35%	97.37%
2/1/2018	66			US190WC	25300	2.448	x	95.12%	94.40%	97.95%	95.72%
	67				25400	2.448	x	94.10%	93.74%	97.66%	94.81%
	68				25500	2.448	x	96.76%	94.14%	96.77%	96.83%
	69				25610	2.448	x	95.96%	93.81%	96.89%	96.59%
	70				25700	2.448	x	93.48%	91.00%	94.96%	93.83%

Contractor Data - date unknown	71	H.010480	I-20	I20BC2	66242	2.489	x	91.23%	x	x	93.87%
	72				66550	2.489	x	90.66%	x	x	94.00%
	73				67000	2.489	x	89.43%	x	x	92.26%
	74				67114	2.489	x	90.20%	x	x	93.10%
	75				67300	2.489	x	86.86%	x	x	92.52%
	76				67600	2.489	x	90.53%	x	x	92.52%
	77				68319	2.489	x	87.95%	x	x	93.42%
	78				68345	2.489	x	x	x	x	92.72%
	79				68400	2.489	x	x	x	x	94.52%
	80				69416	2.489	x	x	x	x	95.29%
	81				69572	2.489	x	x	x	x	92.65%
	82				71064	2.489	x	x	x	x	93.49%
	83				71119	2.489	x	90.33%	84.09%	x	93.68%
	84				72234	2.489	x	90.66%	84.99%	x	93.75%
	85				72584	2.489	x	92.59%	85.18%	x	93.75%
	86				73314	2.489	x	93.87%	84.67%	x	95.29%
	87				73641	2.489	x	91.62%	x	x	93.17%
	88				73710	2.489	x	92.97%	x	x	95.03%
	89				74516	2.489	x	89.95%	x	x	92.78%
	90				74628	2.489	x	92.07%	x	x	93.17%
	91				75062	2.489	x	91.23%	x	x	93.10%
	92				76492	2.489	x	92.91%	x	x	94.39%
	93				77119	2.489	x	92.52%	x	x	93.87%
	94				78916	2.489	x	89.82%	x	x	92.65%
	95				79053	2.489	x	90.27%	x	x	93.23%
	96				79144	2.489	x	90.20%	x	x	92.97%
	97				79424	2.489	x	91.23%	x	x	93.17%
	98				80400	2.489	x	91.69%	x	x	93.94%
	99				80400	2.489	x	90.66%	x	x	92.59%
	100				80407	2.489	x	91.69%	x	x	93.10%
	101				81124	2.489	x	90.85%	x	x	92.59%
	102				81216	2.489	x	92.01%	x	x	94.39%
	103				81625	2.489	x	90.20%	x	x	92.59%
	104				81625	2.489	x	91.69%	x	x	92.26%
	105				82070	2.489	x	91.75%	x	x	92.97%
	106				82070	2.489	x	89.95%	x	x	91.75%
	107				82225	2.489	x	89.88%	x	x	91.04%
	108				82371	2.489	x	92.26%	x	x	94.39%
	109				82434	2.489	x	91.30%	x	x	92.65%
	110				82446	2.489	x	92.97%	86.99%	x	93.17%
	111				83383	2.489	x	92.84%	x	x	93.17%

	112				83614	2.489	x	90.98%	x	x	93.75%
	113				83673	2.489	x	91.23%	x	x	93.04%
	114				84147	2.489	x	91.11%	x	x	93.23%
	115				84917	2.489	x	91.43%	x	x	93.87%
	116				85319	2.489	x	91.04%	x	x	93.17%
	117				85470	2.489	x	90.78%	84.60%	x	92.84%
	118				85500	2.489	x	92.46%	82.09%	x	94.33%
	119				85592	2.489	x	92.26%	x	x	92.97%
	120				85704	2.489	x	90.33%	x	x	92.39%
	121				85925	2.489	x	91.11%	83.12%	x	92.91%
	122				85930	2.489	x	92.84%	x	x	92.59%
	123				86116	2.489	x	91.62%	x	x	93.68%
	124				86492	2.489	x	93.62%	85.44%	x	94.97%
	125				86671	2.489	x	92.39%	x	x	94.07%
	126				87486	2.489	x	91.69%	x	x	92.78%
	127				87981	2.489	x	92.59%	85.96%	x	94.65%
	128				88815	2.489	x	92.39%	x	x	94.07%
	129				88846	2.489	x	90.14%	x	x	93.36%
	130				88854	2.489	x	92.01%	x	x	93.75%
	131				90334	2.489	x	90.85%	x	x	92.52%
	132				90678	2.489	x	90.27%	x	x	92.97%
	133				91066	2.489	x	90.27%	x	x	92.78%
	134				92415	2.489	x	90.91%	x	x	93.87%
	135				92506	2.489	x	x	x	x	95.16%
	136				92624	2.489	x	x	x	x	96.06%
	137				92959	2.489	x	x	x	x	93.36%
	138				93263	2.489	x	x	x	x	95.16%
	139				93564	2.489	x	x	x	x	96.00%
	140				94382	2.489	x	90.40%	x	x	92.33%
	141				94778	2.489	x	90.33%	x	x	92.59%
	142				95115	2.489	x	89.82%	x	x	92.59%
	143				95313	2.489	x	x	x	x	92.52%
	144				95652	2.489	x	90.85%	x	x	92.65%
	145				96154	2.489	x	91.88%	x	x	93.36%
	146				96419	2.489	x	90.33%	84.67%	x	92.39%
	147				96615	2.489	x	90.08%	83.77%	x	92.39%
	148				97482	2.489	x	89.82%	83.89%	x	93.04%
	149				97994	2.489	x	90.85%	84.41%	x	93.42%
	150				98216	2.489	x	93.04%	84.54%	x	94.00%
	151				98661	2.489	x	91.94%	84.80%	x	94.26%
	152				98782	2.489	x	91.43%	84.86%	x	93.23%

Date	Point	DOTD Project #	Route	Mix ID	Station #	Gmm	NDG	TLNDG	NNDG-1	NNDG-2	Core
							Density (%Gmm) - No Offset				
	153				99214	2.489	x	90.33%	84.67%	x	93.30%
	154	H.011594	LA 485	LA485BC	675	2.475	x	96.67%	89.16%	x	95.31%
	155				1050	2.475	x	97.13%	89.55%	x	95.51%
	156				1900	2.475	x	96.74%	89.23%	x	95.77%
	157				2575	2.475	x	97.45%	91.10%	x	96.35%
	158				2800	2.475	x	95.38%	88.25%	x	95.57%
	159				2910	2.475	x	94.99%	87.54%	x	96.74%
	160				6075	2.475	x	95.96%	88.84%	x	96.09%
	161				6910	2.475	x	95.51%	87.80%	x	95.83%
	162				8020	2.475	x	95.51%	88.38%	x	94.79%
	163				10100	2.475	x	97.13%	87.09%	x	95.05%
	164				10930	2.475	x	96.87%	89.36%	x	96.09%
	165				12050	2.475	x	95.70%	87.35%	x	95.70%
	166				12710	2.475	x	96.93%	89.87%	x	94.41%
	167				14110	2.475	x	95.05%	89.16%	x	97.32%
	168				14375	2.475	x	95.96%	88.32%	x	95.05%
	169				15930	2.475	x	96.48%	88.84%	x	94.21%
	170				16825	2.475	x	96.28%	89.23%	x	93.82%
	171				17550	2.475	x	97.00%	90.26%	x	95.83%
	172				18910	2.475	x	98.36%	89.87%	x	97.77%
	173				18950	2.475	x	94.21%	88.84%	x	96.61%
	174				20065	2.475	x	96.61%	90.52%	x	95.70%
	175				20910	2.475	x	97.38%	90.00%	x	96.41%
	176				22370	2.475	x	95.70%	88.06%	x	94.86%
	177				23550	2.475	x	96.54%	89.68%	x	96.09%
	178				24575	2.475	x	96.74%	89.81%	x	96.28%
	179				24950	2.475	x	98.29%	89.94%	x	95.64%
	180				25910	2.475	x	96.48%	89.87%	x	95.51%
	181				26000	2.475	x	96.35%	89.55%	x	94.86%
	182				27100	2.475	x	95.25%	89.10%	x	94.92%
	183				28100	2.475	x	96.48%	89.48%	x	96.02%
	184				29175	2.475	x	95.70%	89.03%	x	95.89%
	185				30510	2.475	x	94.86%	88.32%	x	95.64%
	186				30910	2.475	x	98.61%	89.55%	x	95.57%
	187				32000	2.475	x	96.87%	90.13%	x	96.09%
	188				32175	2.475	x	95.70%	88.12%	x	95.51%
	189				34250	2.475	x	96.02%	88.00%	x	96.15%
	190				37010	2.475	x	96.54%	89.03%	x	95.83%

3/23/2017	1	H.012291	Thibodaux	ThibBC	31880	2.489	95.07%	x	94.91%	94.22%	95.52%
	2				31780	2.489	93.59%	x	93.04%	93.96%	93.86%
	3				31669	2.489	90.81%	x	91.56%	93.06%	90.39%
	4				31554	2.489	95.17%	x	95.36%	94.54%	95.19%
	5				31431	2.489	94.68%	x	94.45%	93.53%	94.35%
4/6/2017	6	H.009658	US 90	US90WC	50300	2.463	94.07%	x	94.07%	93.52%	94.15%
	7				50400	2.463	94.79%	x	94.01%	93.26%	93.43%
	8				50500	2.463	90.49%	x	90.17%	91.05%	89.71%
	9				50600	2.463	91.01%	x	90.43%	91.31%	91.10%
	10				50700	2.463	90.69%	x	92.38%	91.90%	92.65%
6/27/2017 - 6/28/2017	11	H.010480	I-20	I20BC1	96875	2.494	94.13%	x	92.37%	92.62%	93.07%
	12				97075	2.494	91.89%	x	93.14%	92.92%	92.75%
	13				97275	2.494	88.99%	x	91.35%	91.37%	90.64%
	14				97475	2.494	95.48%	x	92.95%	92.91%	93.07%
	15				97875	2.494	92.34%	x	93.02%	93.01%	93.31%
	16				98075	2.494	93.36%	x	93.14%	92.73%	93.60%
	17				98275	2.494	92.53%	x	92.50%	92.52%	92.37%
	18				98475	2.494	92.34%	x	92.82%	92.58%	93.20%
	19				98875	2.494	90.09%	x	91.02%	91.64%	90.87%
	20				99075	2.494	92.21%	x	92.31%	92.64%	92.89%
	21				99275	2.494	89.70%	x	92.82%	93.10%	93.99%
	22				99475	2.494	89.96%	x	92.76%	93.15%	93.27%
	23				80700	2.494	90.60%	x	89.80%	91.04%	92.21%
	24				80900	2.494	92.72%	x	92.37%	91.70%	93.27%
	25				81100	2.494	90.73%	x	91.28%	91.62%	92.13%
	26				81300	2.494	90.79%	x	91.99%	91.92%	92.47%
	27				78200	2.494	89.12%	x	91.02%	89.78%	91.30%
	28				78400	2.494	90.28%	x	91.15%	87.85%	92.50%
	29				78600	2.494	88.42%	x	91.73%	92.06%	94.26%
	30				78800	2.494	97.73%	x	90.90%	91.86%	93.06%
7/26/2017	31	H.011327	US 90	US90SMA	17500	2.397	x	x	92.78%	93.27%	92.58%
	32				17550	2.397	x	x	92.04%	92.75%	92.20%
	33				17600	2.397	x	x	95.25%	95.16%	94.26%
	34				17650	2.397	x	x	96.99%	95.50%	96.25%
	35				17700	2.397	x	x	95.05%	95.45%	96.84%
	36				17750	2.397	x	x	94.85%	94.42%	94.44%
	37				17800	2.397	x	x	95.52%	95.24%	94.95%
	38				17850	2.397	x	x	95.99%	94.95%	94.18%
	39				17900	2.397	x	x	98.26%	96.43%	95.65%
	40				17950	2.397	x	x	90.57%	95.27%	94.37%

10/18/2017	41	H.010558	I-12	I12BC	25700	2.505	x	95.35%	96.04%	96.63%	95.95%
	42				25750	2.505	x	95.35%	96.62%	96.95%	96.27%
	43				25800	2.505	x	98.90%	99.12%	96.78%	97.00%
	44				25850	2.505	x	94.39%	95.08%	95.59%	96.59%
	45				25900	2.505	x	97.94%	95.08%	96.01%	96.15%
	46				25700	2.505	x	92.92%	92.72%	95.52%	94.47%
	47				25750	2.505	x	95.00%	93.93%	94.76%	94.08%
	48				25800	2.505	x	97.14%	94.70%	94.88%	95.29%
	49				25850	2.505	x	92.79%	92.53%	94.24%	94.49%
	50				25900	2.505	x	95.92%	97.13%	95.71%	95.48%
11/27/2017	51	H.012128	LA 98	LA98BC	30400	2.474	x	96.46%	96.45%	95.98%	96.98%
	52				30350	2.474	x	94.38%	95.09%	95.39%	94.74%
	53				30300	2.474	x	93.19%	93.86%	95.01%	94.17%
	54				30250	2.474	x	96.55%	95.93%	95.61%	95.49%
	55				30200	2.474	x	98.11%	97.36%	96.70%	97.30%
12/21/2017	56	H.009549	US 190	US190BC1	21600	2.464	x	94.41%	93.84%	95.18%	94.60%
	57				21700	2.464	x	96.23%	95.07%	95.32%	97.19%
	58				21800	2.464	x	96.17%	95.59%	95.61%	95.60%
	59				21900	2.464	x	95.42%	96.50%	96.04%	95.30%
	60				22000	2.464	x	96.26%	97.48%	96.35%	95.80%
12/29/2017	61			US190BC2	25400	2.450	x	97.92%	96.51%	95.84%	96.11%
	62				25500	2.450	x	94.78%	94.35%	94.49%	93.44%
	63				25610	2.450	x	89.05%	90.56%	92.94%	90.42%
	64				25700	2.450	x	96.25%	96.77%	95.50%	96.11%
	65				25800	2.450	x	95.46%	95.27%	94.68%	97.37%
2/1/2018	66			US190WC	25300	2.448	x	95.59%	96.53%	96.66%	95.72%
	67				25400	2.448	x	94.57%	95.88%	96.37%	94.81%
	68				25500	2.448	x	97.22%	96.27%	95.48%	96.83%
	69				25610	2.448	x	96.43%	95.95%	95.60%	96.59%
	70				25700	2.448	x	93.95%	93.13%	93.67%	93.83%
Contractor Data - date unknown	71	H.010480	I-20	I20BC2	66242	2.489	x	93.08%	x	x	93.87%
	72				66550	2.489	x	92.50%	x	x	94.00%
	73				67000	2.489	x	91.27%	x	x	92.26%
	74				67114	2.489	x	92.05%	x	x	93.10%
	75				67300	2.489	x	88.70%	x	x	92.52%
	76				67600	2.489	x	92.37%	x	x	92.52%
	77				68319	2.489	x	89.79%	x	x	93.42%
	78				68345	2.489	x	x	x	x	92.72%
	79				68400	2.489	x	x	x	x	94.52%
	80				69416	2.489	x	x	x	x	95.29%
	81				69572	2.489	x	x	x	x	92.65%

	82				71064	2.489	x	x	x	x	93.49%
	83				71119	2.489	x	92.17%	92.83%	x	93.68%
	84				72234	2.489	x	92.50%	93.73%	x	93.75%
	85				72584	2.489	x	94.43%	93.93%	x	93.75%
	86				73314	2.489	x	95.72%	93.41%	x	95.29%
	87				73641	2.489	x	93.46%	x	x	93.17%
	88				73710	2.489	x	94.81%	x	x	95.03%
	89				74516	2.489	x	91.79%	x	x	92.78%
	90				74628	2.489	x	93.91%	x	x	93.17%
	91				75062	2.489	x	93.08%	x	x	93.10%
	92				76492	2.489	x	94.75%	x	x	94.39%
	93				77119	2.489	x	94.36%	x	x	93.87%
	94				78916	2.489	x	91.66%	x	x	92.65%
	95				79053	2.489	x	92.11%	x	x	93.23%
	96				79144	2.489	x	92.05%	x	x	92.97%
	97				79424	2.489	x	93.08%	x	x	93.17%
	98				80400	2.489	x	93.53%	x	x	93.94%
	99				80400	2.489	x	92.50%	x	x	92.59%
	100				80407	2.489	x	93.53%	x	x	93.10%
	101				81124	2.489	x	92.69%	x	x	92.59%
	102				81216	2.489	x	93.85%	x	x	94.39%
	103				81625	2.489	x	92.05%	x	x	92.59%
	104				81625	2.489	x	93.53%	x	x	92.26%
	105				82070	2.489	x	93.59%	x	x	92.97%
	106				82070	2.489	x	91.79%	x	x	91.75%
	107				82225	2.489	x	91.72%	x	x	91.04%
	108				82371	2.489	x	94.11%	x	x	94.39%
	109				82434	2.489	x	93.14%	x	x	92.65%
	110				82446	2.489	x	94.81%	95.73%	x	93.17%
	111				83383	2.489	x	94.69%	x	x	93.17%
	112				83614	2.489	x	92.82%	x	x	93.75%
	113				83673	2.489	x	93.08%	x	x	93.04%
	114				84147	2.489	x	92.95%	x	x	93.23%
	115				84917	2.489	x	93.27%	x	x	93.87%
	116				85319	2.489	x	92.88%	x	x	93.17%
	117				85470	2.489	x	92.63%	93.35%	x	92.84%
	118				85500	2.489	x	94.30%	90.84%	x	94.33%
	119				85592	2.489	x	94.11%	x	x	92.97%
	120				85704	2.489	x	92.17%	x	x	92.39%
	121				85925	2.489	x	92.95%	91.87%	x	92.91%
	122				85930	2.489	x	94.69%	x	x	92.59%

	123				86116	2.489	x	93.46%	x	x	93.68%
	124				86492	2.489	x	95.46%	94.18%	x	94.97%
	125				86671	2.489	x	94.24%	x	x	94.07%
	126				87486	2.489	x	93.53%	x	x	92.78%
	127				87981	2.489	x	94.43%	94.70%	x	94.65%
	128				88815	2.489	x	94.24%	x	x	94.07%
	129				88846	2.489	x	91.98%	x	x	93.36%
	130				88854	2.489	x	93.85%	x	x	93.75%
	131				90334	2.489	x	92.69%	x	x	92.52%
	132				90678	2.489	x	92.11%	x	x	92.97%
	133				91066	2.489	x	92.11%	x	x	92.78%
	134				92415	2.489	x	92.75%	x	x	93.87%
	135				92506	2.489	x	x	x	x	95.16%
	136				92624	2.489	x	x	x	x	96.06%
	137				92959	2.489	x	x	x	x	93.36%
	138				93263	2.489	x	x	x	x	95.16%
	139				93564	2.489	x	x	x	x	96.00%
	140				94382	2.489	x	92.24%	x	x	92.33%
	141				94778	2.489	x	92.17%	x	x	92.59%
	142				95115	2.489	x	91.66%	x	x	92.59%
	143				95313	2.489	x	x	x	x	92.52%
	144				95652	2.489	x	92.69%	x	x	92.65%
	145				96154	2.489	x	93.72%	x	x	93.36%
	146				96419	2.489	x	92.17%	93.41%	x	92.39%
	147				96615	2.489	x	91.92%	92.51%	x	92.39%
	148				97482	2.489	x	91.66%	92.64%	x	93.04%
	149				97994	2.489	x	92.69%	93.15%	x	93.42%
	150				98216	2.489	x	94.88%	93.28%	x	94.00%
	151				98661	2.489	x	93.78%	93.54%	x	94.26%
	152				98782	2.489	x	93.27%	93.60%	x	93.23%
	153				99214	2.489	x	92.17%	93.41%	x	93.30%
	154	H.011594	LA 485	LA485BC	675	2.475	x	95.70%	95.40%	x	95.31%
	155				1050	2.475	x	96.15%	95.79%	x	95.51%
	156				1900	2.475	x	95.77%	95.47%	x	95.77%
	157				2575	2.475	x	96.48%	97.35%	x	96.35%
	158				2800	2.475	x	94.41%	94.50%	x	95.57%
	159				2910	2.475	x	94.02%	93.78%	x	96.74%
	160				6075	2.475	x	94.99%	95.08%	x	96.09%
	161				6910	2.475	x	94.54%	94.04%	x	95.83%
	162				8020	2.475	x	94.54%	94.63%	x	94.79%
	163				10100	2.475	x	96.15%	93.33%	x	95.05%

	164				10930	2.475	x	95.89%	95.60%	x	96.09%
	165				12050	2.475	x	94.73%	93.59%	x	95.70%
	166				12710	2.475	x	95.96%	96.11%	x	94.41%
	167				14110	2.475	x	94.08%	95.40%	x	97.32%
	168				14375	2.475	x	94.99%	94.56%	x	95.05%
	169				15930	2.475	x	95.51%	95.08%	x	94.21%
	170				16825	2.475	x	95.31%	95.47%	x	93.82%
	171				17550	2.475	x	96.02%	96.50%	x	95.83%
	172				18910	2.475	x	97.38%	96.11%	x	97.77%
	173				18950	2.475	x	93.24%	95.08%	x	96.61%
	174				20065	2.475	x	95.64%	96.76%	x	95.70%
	175				20910	2.475	x	96.41%	96.24%	x	96.41%
	176				22370	2.475	x	94.73%	94.30%	x	94.86%
	177				23550	2.475	x	95.57%	95.92%	x	96.09%
	178				24575	2.475	x	95.77%	96.05%	x	96.28%
	179				24950	2.475	x	97.32%	96.18%	x	95.64%
	180				25910	2.475	x	95.51%	96.11%	x	95.51%
	181				26000	2.475	x	95.38%	95.79%	x	94.86%
	182				27100	2.475	x	94.28%	95.34%	x	94.92%
	183				28100	2.475	x	95.51%	95.73%	x	96.02%
	184				29175	2.475	x	94.73%	95.27%	x	95.89%
	185				30510	2.475	x	93.89%	94.56%	x	95.64%
	186				30910	2.475	x	97.64%	95.79%	x	95.57%
	187				32000	2.475	x	95.89%	96.37%	x	96.09%
	188				32175	2.475	x	94.73%	94.37%	x	95.51%
	189				34250	2.475	x	95.05%	94.24%	x	96.15%
	190				37010	2.475	x	95.57%	95.27%	x	95.83%

Table 23
Unit weight (lbs./ft^3) density results

Date	Point	DOTD Project #	Route	Mix ID	Station #	Gmm	NDG	TLNDG	NNDG-1	NNDG-2	Core
							Unit Wt. (lbs/ft3) - No Offset				
3/23/2017	1	H.012291	Thibodaux	ThibBC	31880	2.489	148.57	x	136.00	150.00	148.36
	2				31780	2.489	146.27	x	133.10	149.60	145.78
	3				31669	2.489	141.95	x	130.80	148.20	140.38
	4				31554	2.489	148.74	x	136.70	150.50	147.85
	5				31431	2.489	147.97	x	135.30	148.93	146.54
4/6/2017	6	H.009658	US 90	US90WC	50300	2.463	146.40	x	137.00	146.50	144.70
	7				50400	2.463	147.50	x	136.90	146.10	143.60
	8				50500	2.463	140.90	x	131.00	142.70	137.88
	9				50600	2.463	141.70	x	131.40	143.10	140.02
	10				50700	2.463	141.20	x	134.40	144.00	142.39
6/27/2017 - 6/28/2017	11	H.010480	I-20	I20BC1	96875	2.494	142.10	x	126.20	142.47	144.85
	12				97075	2.494	138.60	x	127.40	142.94	144.34
	13				97275	2.494	134.10	x	124.60	140.51	141.05
	14				97475	2.494	144.20	x	127.10	142.92	144.84
	15				97875	2.494	139.30	x	127.20	143.07	145.21
	16				98075	2.494	140.90	x	127.40	142.64	145.66
	17				98275	2.494	139.60	x	126.40	142.32	143.76
	18				98475	2.494	139.30	x	126.90	142.41	145.05
	19				98875	2.494	135.80	x	124.10	140.94	141.42
	20				99075	2.494	139.10	x	126.10	142.49	144.56
	21				99275	2.494	135.20	x	126.90	143.22	146.27
	22				99475	2.494	135.60	x	126.80	143.28	145.16
	23				80700	2.494	136.60	x	122.20	140.00	143.51
	24				80900	2.494	139.90	x	126.20	141.04	145.15
	25				81100	2.494	136.80	x	124.50	140.90	143.37
	26				81300	2.494	136.90	x	125.60	141.38	143.91
	27				78200	2.494	134.30	x	124.10	138.05	142.09
	28				78400	2.494	136.10	x	124.30	135.05	143.96
	29				78600	2.494	133.20	x	125.20	141.59	146.69
	30				78800	2.494	147.70	x	123.90	141.28	144.82
7/26/2017	31	H.011327	US 90	US90SMA	17500	2.397	x	x	125.50	141.51	138.48
	32				17550	2.397	x	x	124.40	140.73	137.90
	33				17600	2.397	x	x	129.20	144.32	140.99
	34				17650	2.397	x	x	131.80	144.83	143.96
	35				17700	2.397	x	x	128.90	144.75	144.84
	36				17750	2.397	x	x	128.60	143.22	141.26

	37				17800	2.397	x	x	129.60	144.44	142.02
	38				17850	2.397	x	x	130.30	144.02	140.86
	39				17900	2.397	x	x	133.70	146.23	143.07
	40				17950	2.397	x	x	122.20	144.49	141.16
10/18/2017	41	H.010558	I-12	I12BC	25700	2.505	x	142.25	140.50	151.86	149.97
	42				25750	2.505	x	142.25	141.40	152.34	150.48
	43				25800	2.505	x	147.80	145.30	152.08	151.62
	44				25850	2.505	x	140.75	139.00	150.22	150.98
	45				25900	2.505	x	146.30	139.00	150.88	150.30
	46				25700	2.505	x	138.45	135.30	150.11	147.66
	47				25750	2.505	x	141.70	137.20	148.92	147.05
	48				25800	2.505	x	145.05	138.40	149.12	148.94
	49				25850	2.505	x	138.25	135.00	148.11	147.69
	50				25900	2.505	x	143.13	142.20	150.42	149.25
11/27/2017	51	H.012128	LA 98	LA98BC	30400	2.474	x	149.85	143.80	151.53	149.71
	52				30350	2.474	x	146.60	141.70	150.62	146.26
	53				30300	2.474	x	144.75	139.80	150.03	145.38
	54				30250	2.474	x	149.95	143.00	150.96	147.42
	55				30200	2.474	x	152.35	145.20	152.64	150.20
12/21/2017	56	H.009549	US 190	US190BC1	21600	2.464	x	145.40	142.40	149.63	145.49
	57				21700	2.464	x	148.20	144.30	149.84	147.34
	58				21800	2.464	x	148.10	145.10	150.29	147.03
	59				21900	2.464	x	146.95	146.50	150.95	146.57
	60				22000	2.464	x	148.25	148.00	151.43	149.48
12/29/2017	61			US190BC2	25400	2.450	x	146.50	147.00	152.13	146.94
	62				25500	2.450	x	141.70	143.70	150.06	142.85
	63				25610	2.450	x	132.95	137.90	147.70	138.24
	64				25700	2.450	x	143.95	147.40	151.61	146.94
	65				25800	2.450	x	142.75	145.10	150.36	148.85
2/1/2018	66			US190WC	25300	2.448	x	145.30	144.20	149.63	146.21
	67				25400	2.448	x	143.75	143.20	149.19	144.82
	68				25500	2.448	x	147.80	143.80	147.83	147.91
	69				25610	2.448	x	146.59	143.30	148.01	147.54
	70				25700	2.448	x	142.80	139.00	145.06	143.33
Contractor Data - date unknown	71	H.010480	I-20	I20BC2	66242	2.489	x	141.70	x	x	145.80
	72				66550	2.489	x	140.80	x	x	146.00
	73				67000	2.489	x	138.90	x	x	143.30
	74				67114	2.489	x	140.10	x	x	144.60
	75				67300	2.489	x	134.90	x	x	143.70
	76				67600	2.489	x	140.60	x	x	143.70
	77				68319	2.489	x	136.60	x	x	145.10

	78				68345	2.489	x	x	x	x	144.00
	79				68400	2.489	x	x	x	x	146.80
	80				69416	2.489	x	x	x	x	148.00
	81				69572	2.489	x	x	x	x	143.90
	82				71064	2.489	x	x	x	x	145.20
	83				71119	2.489	x	140.30	130.60	x	145.50
	84				72234	2.489	x	140.80	132.00	x	145.60
	85				72584	2.489	x	143.80	132.30	x	145.60
	86				73314	2.489	x	145.80	131.50	x	148.00
	87				73641	2.489	x	142.30	x	x	144.70
	88				73710	2.489	x	144.40	x	x	147.60
	89				74516	2.489	x	139.70	x	x	144.10
	90				74628	2.489	x	143.00	x	x	144.70
	91				75062	2.489	x	141.70	x	x	144.60
	92				76492	2.489	x	144.30	x	x	146.60
	93				77119	2.489	x	143.70	x	x	145.80
	94				78916	2.489	x	139.50	x	x	143.90
	95				79053	2.489	x	140.20	x	x	144.80
	96				79144	2.489	x	140.10	x	x	144.40
	97				79424	2.489	x	141.70	x	x	144.70
	98				80400	2.489	x	142.40	x	x	145.90
	99				80400	2.489	x	140.80	x	x	143.80
	100				80407	2.489	x	142.40	x	x	144.60
	101				81124	2.489	x	141.10	x	x	143.80
	102				81216	2.489	x	142.90	x	x	146.60
	103				81625	2.489	x	140.10	x	x	143.80
	104				81625	2.489	x	142.40	x	x	143.30
	105				82070	2.489	x	142.50	x	x	144.40
	106				82070	2.489	x	139.70	x	x	142.50
	107				82225	2.489	x	139.60	x	x	141.40
	108				82371	2.489	x	143.30	x	x	146.60
	109				82434	2.489	x	141.80	x	x	143.90
	110				82446	2.489	x	144.40	135.10	x	144.70
	111				83383	2.489	x	144.20	x	x	144.70
	112				83614	2.489	x	141.30	x	x	145.60
	113				83673	2.489	x	141.70	x	x	144.50
	114				84147	2.489	x	141.50	x	x	144.80
	115				84917	2.489	x	142.00	x	x	145.80
	116				85319	2.489	x	141.40	x	x	144.70
	117				85470	2.489	x	141.00	131.40	x	144.20
	118				85500	2.489	x	143.60	127.50	x	146.50

	119				85592	2.489	x	143.30	x	x	144.40
	120				85704	2.489	x	140.30	x	x	143.50
	121				85925	2.489	x	141.50	129.10	x	144.30
	122				85930	2.489	x	144.20	x	x	143.80
	123				86116	2.489	x	142.30	x	x	145.50
	124				86492	2.489	x	145.40	132.70	x	147.50
	125				86671	2.489	x	143.50	x	x	146.10
	126				87486	2.489	x	142.40	x	x	144.10
	127				87981	2.489	x	143.80	133.50	x	147.00
	128				88815	2.489	x	143.50	x	x	146.10
	129				88846	2.489	x	140.00	x	x	145.00
	130				88854	2.489	x	142.90	x	x	145.60
	131				90334	2.489	x	141.10	x	x	143.70
	132				90678	2.489	x	140.20	x	x	144.40
	133				91066	2.489	x	140.20	x	x	144.10
	134				92415	2.489	x	141.20	x	x	145.80
	135				92506	2.489	x	x	x	x	147.80
	136				92624	2.489	x	x	x	x	149.20
	137				92959	2.489	x	x	x	x	145.00
	138				93263	2.489	x	x	x	x	147.80
	139				93564	2.489	x	x	x	x	149.10
	140				94382	2.489	x	140.40	x	x	143.40
	141				94778	2.489	x	140.30	x	x	143.80
	142				95115	2.489	x	139.50	x	x	143.80
	143				95313	2.489	x	x	x	x	143.70
	144				95652	2.489	x	141.10	x	x	143.90
	145				96154	2.489	x	142.70	x	x	145.00
	146				96419	2.489	x	140.30	131.50	x	143.50
	147				96615	2.489	x	139.90	130.10	x	143.50
	148				97482	2.489	x	139.50	130.30	x	144.50
	149				97994	2.489	x	141.10	131.10	x	145.10
	150				98216	2.489	x	144.50	131.30	x	146.00
	151				98661	2.489	x	142.80	131.70	x	146.40
	152				98782	2.489	x	142.00	131.80	x	144.80
	153				99214	2.489	x	140.30	131.50	x	144.90
	154	H.011594	LA 485	LA485BC	675	2.475	x	149.30	137.70	x	147.20
	155				1050	2.475	x	150.00	138.30	x	147.50
	156				1900	2.475	x	149.40	137.80	x	147.90
	157				2575	2.475	x	150.50	140.70	x	148.80
	158				2800	2.475	x	147.30	136.30	x	147.60
	159				2910	2.475	x	146.70	135.20	x	149.40

	160				6075	2.475	x	148.20	137.20	x	148.40
	161				6910	2.475	x	147.50	135.60	x	148.00
	162				8020	2.475	x	147.50	136.50	x	146.40
	163				10100	2.475	x	150.00	134.50	x	146.80
	164				10930	2.475	x	149.60	138.00	x	148.40
	165				12050	2.475	x	147.80	134.90	x	147.80
	166				12710	2.475	x	149.70	138.80	x	145.80
	167				14110	2.475	x	146.80	137.70	x	150.30
	168				14375	2.475	x	148.20	136.40	x	146.80
	169				15930	2.475	x	149.00	137.20	x	145.50
	170				16825	2.475	x	148.70	137.80	x	144.90
	171				17550	2.475	x	149.80	139.40	x	148.00
	172				18910	2.475	x	151.90	138.80	x	151.00
	173				18950	2.475	x	145.50	137.20	x	149.20
	174				20065	2.475	x	149.20	139.80	x	147.80
	175				20910	2.475	x	150.40	139.00	x	148.90
	176				22370	2.475	x	147.80	136.00	x	146.50
	177				23550	2.475	x	149.10	138.50	x	148.40
	178				24575	2.475	x	149.40	138.70	x	148.70
	179				24950	2.475	x	151.80	138.90	x	147.70
	180				25910	2.475	x	149.00	138.80	x	147.50
	181				26000	2.475	x	148.80	138.30	x	146.50
	182				27100	2.475	x	147.10	137.60	x	146.60
	183				28100	2.475	x	149.00	138.20	x	148.30
	184				29175	2.475	x	147.80	137.50	x	148.10
	185				30510	2.475	x	146.50	136.40	x	147.70
	186				30910	2.475	x	152.30	138.30	x	147.60
	187				32000	2.475	x	149.60	139.20	x	148.40
	188				32175	2.475	x	147.80	136.10	x	147.50
	189				34250	2.475	x	148.30	135.90	x	148.50
	190				37010	2.475	x	149.10	137.50	x	148.00

Date	Point	DOTD Project #	Route	Mix ID	Station #	Gmm	NDG	TLNDG	NNDG-1	NNDG-2	Core
							Unit Wt. (lbs/ft3) - With Offset				
3/23/2017	1	H.012291	Thibodaux	ThibBC	31880	2.489	147.65	x	147.40	146.33	148.36
	2				31780	2.489	145.35	x	144.50	145.93	145.78
	3				31669	2.489	141.03	x	142.20	144.53	140.38
	4				31554	2.489	147.82	x	148.10	146.83	147.85
	5				31431	2.489	147.05	x	146.70	145.27	146.54
4/6/2017	6	H.009658	US 90	US90 WC	50300	2.463	144.58	x	144.58	143.74	144.70
	7				50400	2.463	145.68	x	144.48	143.34	143.60

	8				50500	2.463	139.08	x	138.58	139.94	137.88
	9				50600	2.463	139.88	x	138.98	140.34	140.02
	10				50700	2.463	139.38	x	141.98	141.24	142.39
6/27/2017 - 6/28/2017	11	H.010480	I-20	I20BC1	96875	2.494	146.50	x	143.76	144.15	144.85
	12				97075	2.494	143.00	x	144.96	144.61	144.34
	13				97275	2.494	138.50	x	142.16	142.19	141.05
	14				97475	2.494	148.60	x	144.66	144.59	144.84
	15				97875	2.494	143.70	x	144.76	144.74	145.21
	16				98075	2.494	145.30	x	144.96	144.31	145.66
	17				98275	2.494	144.00	x	143.96	143.99	143.76
	18				98475	2.494	143.70	x	144.46	144.08	145.05
	19				98875	2.494	140.20	x	141.66	142.62	141.42
	20				99075	2.494	143.50	x	143.66	144.16	144.56
	21				99275	2.494	139.60	x	144.46	144.89	146.27
	22				99475	2.494	140.00	x	144.36	144.96	145.16
	23				80700	2.494	141.00	x	139.76	141.68	143.51
	24				80900	2.494	144.30	x	143.76	142.72	145.15
	25				81100	2.494	141.20	x	142.06	142.58	143.37
	26				81300	2.494	141.30	x	143.16	143.05	143.91
	27				78200	2.494	138.70	x	141.66	139.72	142.09
	28				78400	2.494	140.50	x	141.86	136.72	143.96
	29				78600	2.494	137.60	x	142.76	143.26	146.69
	30				78800	2.494	152.10	x	141.46	142.96	144.82
7/26/2017	31	H.011327	US 90	US90SMA	17500	2.397	x	x	138.77	139.51	138.48
	32				17550	2.397	x	x	137.67	138.73	137.90
	33				17600	2.397	x	x	142.47	142.33	140.99
	34				17650	2.397	x	x	145.07	142.84	143.96
	35				17700	2.397	x	x	142.17	142.76	144.84
	36				17750	2.397	x	x	141.87	141.23	141.26
	37				17800	2.397	x	x	142.87	142.45	142.02
	38				17850	2.397	x	x	143.57	142.03	140.86
	39				17900	2.397	x	x	146.97	144.23	143.07
	40				17950	2.397	x	x	135.47	142.49	141.16
10/18/2017	41	H.010558	I-12	I12BC	25700	2.505	x	149.05	150.13	151.05	149.97
	42				25750	2.505	x	149.05	151.03	151.54	150.48
	43				25800	2.505	x	154.60	154.93	151.27	151.62
	44				25850	2.505	x	147.55	148.63	149.41	150.98
	45				25900	2.505	x	153.10	148.63	150.07	150.30
	46				25700	2.505	x	145.25	144.93	149.30	147.66
	47				25750	2.505	x	148.50	146.83	148.12	147.05
	48				25800	2.505	x	151.85	148.03	148.31	148.94

	49				25850	2.505	x	145.05	144.63	147.30	147.69
	50				25900	2.505	x	149.93	151.83	149.61	149.25
11/27/2017	51	H.012128	LA 98	LA98BC	30400	2.474	x	148.95	148.90	148.16	149.71
	52				30350	2.474	x	145.70	146.80	147.26	146.26
	53				30300	2.474	x	143.85	144.90	146.67	145.38
	54				30250	2.474	x	149.05	148.10	147.60	147.42
	55				30200	2.474	x	151.45	150.30	149.28	150.20
12/21/2017	56	H.009549	US 190	US190BC1	21600	2.464	x	145.20	144.32	146.38	145.49
	57				21700	2.464	x	148.00	146.22	146.60	147.34
	58				21800	2.464	x	147.90	147.02	147.04	147.03
	59				21900	2.464	x	146.75	148.42	147.71	146.57
	60				22000	2.464	x	148.05	149.92	148.18	149.48
12/29/2017	61			US190BC2	25400	2.450	x	149.69	147.54	146.52	146.94
	62				25500	2.450	x	144.89	144.24	144.46	142.85
	63				25610	2.450	x	136.14	138.44	142.09	138.24
	64				25700	2.450	x	147.14	147.94	146.00	146.94
	65				25800	2.450	x	145.94	145.64	144.75	148.85
2/1/2018	66			US190WC	25300	2.448	x	146.01	147.46	147.65	146.21
	67				25400	2.448	x	144.46	146.46	147.21	144.82
	68				25500	2.448	x	148.51	147.06	145.84	147.91
	69				25610	2.448	x	147.30	146.56	146.03	147.54
	70				25700	2.448	x	143.51	142.26	143.08	143.33
Contractor Data - date unknown	71	H.010480	I-20	I20BC2	66242	2.489	x	144.56	x	x	145.80
	72				66550	2.489	x	143.66	x	x	146.00
	73				67000	2.489	x	141.76	x	x	143.30
	74				67114	2.489	x	142.96	x	x	144.60
	75				67300	2.489	x	137.76	x	x	143.70
	76				67600	2.489	x	143.46	x	x	143.70
	77				68319	2.489	x	139.46	x	x	145.10
	78				68345	2.489	x	x	x	x	144.00
	79				68400	2.489	x	x	x	x	146.80
	80				69416	2.489	x	x	x	x	148.00
	81				69572	2.489	x	x	x	x	143.90
	82				71064	2.489	x	x	x	x	145.20
	83				71119	2.489	x	143.16	144.18	x	145.50
	84				72234	2.489	x	143.66	145.58	x	145.60
	85				72584	2.489	x	146.66	145.88	x	145.60
	86				73314	2.489	x	148.66	145.08	x	148.00
	87				73641	2.489	x	145.16	x	x	144.70
	88				73710	2.489	x	147.26	x	x	147.60
	89				74516	2.489	x	142.56	x	x	144.10

	90				74628	2.489	x	145.86	x	x	144.70
	91				75062	2.489	x	144.56	x	x	144.60
	92				76492	2.489	x	147.16	x	x	146.60
	93				77119	2.489	x	146.56	x	x	145.80
	94				78916	2.489	x	142.36	x	x	143.90
	95				79053	2.489	x	143.06	x	x	144.80
	96				79144	2.489	x	142.96	x	x	144.40
	97				79424	2.489	x	144.56	x	x	144.70
	98				80400	2.489	x	145.26	x	x	145.90
	99				80400	2.489	x	143.66	x	x	143.80
	100				80407	2.489	x	145.26	x	x	144.60
	101				81124	2.489	x	143.96	x	x	143.80
	102				81216	2.489	x	145.76	x	x	146.60
	103				81625	2.489	x	142.96	x	x	143.80
	104				81625	2.489	x	145.26	x	x	143.30
	105				82070	2.489	x	145.36	x	x	144.40
	106				82070	2.489	x	142.56	x	x	142.50
	107				82225	2.489	x	142.46	x	x	141.40
	108				82371	2.489	x	146.16	x	x	146.60
	109				82434	2.489	x	144.66	x	x	143.90
	110				82446	2.489	x	147.26	148.68	x	144.70
	111				83383	2.489	x	147.06	x	x	144.70
	112				83614	2.489	x	144.16	x	x	145.60
	113				83673	2.489	x	144.56	x	x	144.50
	114				84147	2.489	x	144.36	x	x	144.80
	115				84917	2.489	x	144.86	x	x	145.80
	116				85319	2.489	x	144.26	x	x	144.70
	117				85470	2.489	x	143.86	144.98	x	144.20
	118				85500	2.489	x	146.46	141.08	x	146.50
	119				85592	2.489	x	146.16	x	x	144.40
	120				85704	2.489	x	143.16	x	x	143.50
	121				85925	2.489	x	144.36	142.68	x	144.30
	122				85930	2.489	x	147.06	x	x	143.80
	123				86116	2.489	x	145.16	x	x	145.50
	124				86492	2.489	x	148.26	146.28	x	147.50
	125				86671	2.489	x	146.36	x	x	146.10
	126				87486	2.489	x	145.26	x	x	144.10
	127				87981	2.489	x	146.66	147.08	x	147.00
	128				88815	2.489	x	146.36	x	x	146.10
	129				88846	2.489	x	142.86	x	x	145.00
	130				88854	2.489	x	145.76	x	x	145.60

	131				90334	2.489	x	143.96	x	x	143.70
	132				90678	2.489	x	143.06	x	x	144.40
	133				91066	2.489	x	143.06	x	x	144.10
	134				92415	2.489	x	144.06	x	x	145.80
	135				92506	2.489	x	x	x	x	147.80
	136				92624	2.489	x	x	x	x	149.20
	137				92959	2.489	x	x	x	x	145.00
	138				93263	2.489	x	x	x	x	147.80
	139				93564	2.489	x	x	x	x	149.10
	140				94382	2.489	x	143.26	x	x	143.40
	141				94778	2.489	x	143.16	x	x	143.80
	142				95115	2.489	x	142.36	x	x	143.80
	143				95313	2.489	x	x	x	x	143.70
	144				95652	2.489	x	143.96	x	x	143.90
	145				96154	2.489	x	145.56	x	x	145.00
	146				96419	2.489	x	143.16	145.08	x	143.50
	147				96615	2.489	x	142.76	143.68	x	143.50
	148				97482	2.489	x	142.36	143.88	x	144.50
	149				97994	2.489	x	143.96	144.68	x	145.10
	150				98216	2.489	x	147.36	144.88	x	146.00
	151				98661	2.489	x	145.66	145.28	x	146.40
	152				98782	2.489	x	144.86	145.38	x	144.80
	153				99214	2.489	x	143.16	145.08	x	144.90
	154	H.011594	LA 485	LA485BC	675	2.475	x	147.35	146.93	x	147.20
	155				1050	2.475	x	148.05	147.53	x	147.50
	156				1900	2.475	x	147.45	147.03	x	147.90
	157				2575	2.475	x	148.55	149.93	x	148.80
	158				2800	2.475	x	145.35	145.53	x	147.60
	159				2910	2.475	x	144.75	144.43	x	149.40
	160				6075	2.475	x	146.25	146.43	x	148.40
	161				6910	2.475	x	145.55	144.83	x	148.00
	162				8020	2.475	x	145.55	145.73	x	146.40
	163				10100	2.475	x	148.05	143.73	x	146.80
	164				10930	2.475	x	147.65	147.23	x	148.40
	165				12050	2.475	x	145.85	144.13	x	147.80
	166				12710	2.475	x	147.75	148.03	x	145.80
	167				14110	2.475	x	144.85	146.93	x	150.30
	168				14375	2.475	x	146.25	145.63	x	146.80
	169				15930	2.475	x	147.05	146.43	x	145.50
	170				16825	2.475	x	146.75	147.03	x	144.90
	171				17550	2.475	x	147.85	148.63	x	148.00

	172				18910	2.475	x	149.95	148.03	x	151.00
	173				18950	2.475	x	143.55	146.43	x	149.20
	174				20065	2.475	x	147.25	149.03	x	147.80
	175				20910	2.475	x	148.45	148.23	x	148.90
	176				22370	2.475	x	145.85	145.23	x	146.50
	177				23550	2.475	x	147.15	147.73	x	148.40
	178				24575	2.475	x	147.45	147.93	x	148.70
	179				24950	2.475	x	149.85	148.13	x	147.70
	180				25910	2.475	x	147.05	148.03	x	147.50
	181				26000	2.475	x	146.85	147.53	x	146.50
	182				27100	2.475	x	145.15	146.83	x	146.60
	183				28100	2.475	x	147.05	147.43	x	148.30
	184				29175	2.475	x	145.85	146.73	x	148.10
	185				30510	2.475	x	144.55	145.63	x	147.70
	186				30910	2.475	x	150.35	147.53	x	147.60
	187				32000	2.475	x	147.65	148.43	x	148.40
	188				32175	2.475	x	145.85	145.33	x	147.50
	189				34250	2.475	x	146.35	145.13	x	148.50
	190				37010	2.475	x	147.15	146.73	x	148.00

Table 24
Sand patch results

ASTM E 965										
Date	**Location**	**Layer Type**	**Station**	**Trial**	**Diam. 1 (mm)**	**Diam. 2 (mm)**	**Diam. 3 (mm)**	**Diam. 4 (mm)**	**Average (mm)**	**MATXd (mm)**
10/18/2017	I-12	Binder Course 6"	25700	1	235	235	225	245	235.0	1.153
			25750	2	220	225	240	210	223.8	1.272
			25800	3	225	255	255	240	243.8	1.071
			25850	4	255	235	215	235	235.0	1.153
			25900	5	245	240	240	235	240.0	1.105
10/19/2017	I-12	Binder Course 4"	25700	1	225	245	220	245	233.8	1.165
			25750	2	230	240	230	235	233.8	1.165
			25800	3	260	240	255	250	251.3	1.008
			25850	4	225	215	210	225	218.8	1.330
			25900	5	240	255	255	245	248.8	1.029
11/27/2017	LA 98	Binder Course 2"	30400	1	340	220	310	290	290.0	0.757
			30350	2	300	310	310	305	306.3	0.679
			30300	3	280	295	270	275	280.0	0.812
			30250	4	300	295	295	295	296.3	0.725
			30200	5	300	295	295	295	296.3	0.725
12/21/2017	US 190	Evotherm Binder Course 2"	21600	1	270	290	290	280	282.5	0.798
			21700	2	275	305	290	270	285.0	0.784
			21800	3	280	250	260	270	265.0	0.907
			21900	4	320	280	305	315	305.0	0.684
			22000	5	300	280	290	310	295.0	0.732
12/29/2017	US 190	Plus AC Binder Course 2"	25400	1	290	280	270	280	280.0	0.812
			25500	2	320	340	320	325	326.3	0.598
			25610	3	265	270	270	250	263.8	0.915
			25700	4	250	250	240	230	242.5	1.083
			25800	5	250	250	240	230	242.5	1.083
2/1/2018	US 190	Original Wearing Course 1.5"	25300	1	270	265	265	270	267.5	0.890
			25400	2	255	275	260	260	262.5	0.924
			25500	3	275	280	285	275	278.8	0.819
			25600	4	290	250	270	265	268.8	0.881
			25700	5	250	240	235	250	243.8	1.071

APPENDIX C

Pilot Specification

502.11.2 Density by Non-Destructive Technologies (NDT) (Pilot Specification): In addition to all required quality control testing, contractors may submit quality control density measurements collected using DOTD approved non-destructive technologies (NDT) in accordance with the quality assurance manual. Density measurements reported by NDT devices will be for informational purposes only, such as, to provide supporting documentation for a dispute claim. Density measurements reported by NDT devices will not be used in place of any required quality control or quality assurance testing.

502.11.2.1 Equipment and Operation: Use a non-destructive technologies (NDT) device meeting requirements of AASHTO T-343 or AASHTO T-355.

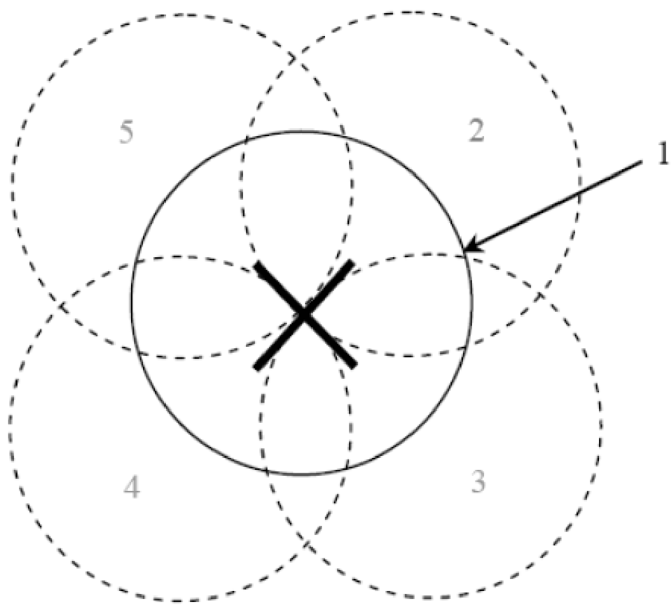
When performing NDT tests, set the device in the single reading and shallow penetration modes. A density measurement will consist of the average of five readings taken in accordance with the reading pattern described by the manufacturers procedure manual. Take readings where the pavement surface is flat and no surface moisture is evident. Use brush to clear loose particles from contact area.

Verify the NDT device operation daily using the standardization plate issued with the gauge. Follow the Manufacturer’s instructions for performing the standardization. Ensure each day’s standardization result is within the limits established by the manufacture.

502.11.2.2 NDT Device Off-set Procedures: Prior to using NDT device measurements, an offset will be determined for each JMF, for each project. This offset will be established during mixture validation in the presence of DOTD personnel. On days when a control strip is being placed, the DOTD personnel must witness the contractor’s personnel standard count procedure. The NDT device will be used to determine an average density from random locations determined by the DOTD personnel. The frequency of testing will be 20 locations within the validation lot. The center location of the device readings will be marked. Core specimens will be extruded from marked location after all NDT reading are conducted at that location. The device readings will be compared with the core densities in order to establish a working offset. The offset will be specific to that device, for that JMF, for that project. In the event that the JMF changes, or a new device is used, a new offset must be established.

Off-set procedures should be followed as listed below:

1. Contractor and DOTD technicians should jointly verify all NDT parameters for each device:
   a. Successful self-test at start up
   b. JMF G_{mm}
   c. Lift thickness
   d. Test mode
   e. Target density
   f. Correct any issue(s) prior to proceeding with field confirmation
2. DOTD personnel will select a random site on the mat:
   a. Location of random spots will be recorded
3. NDT readings should be taken in single mode and reading pattern should follow the 5-point star method as seen below.



4. The QA gauge operator will conduct 50 NDT density tests, 5 readings at each of the 10 random core locations within the validation lot. The 5 readings from each location will be averaged into a single density measurement for that location.
5. Density gauge readings will be recorded on paper and in the density gauge if possible.
6. Follow core sampling, trimming, handling and transport procedures outlined in section 502.11.1.
7. The off-set will be determined by subtracting the device density from the core density. An average offset is determined using the 10 locations. The off-set will be applied on subsequent lots of the same JMF, with the same device,

during the construction of the project.

502.11.2.3 Roadway Testing Procedures: There are typically five sublots for each lot. Mainline and minor mixes may be in the same lot/ sublot. Divide each of the sublots into two segments of approximately equal tonnage each. For each sublot segment, the Department will determine sample locations using random sampling approach. The department will obtain one acceptance device density reading (average of 5 spot readings) at the designated sample location. The contractor will obtain one quality control device density reading (average of 5 spot readings) approximately 12 inches in the direction of travel from the acceptance reading. If the sublot segment has mainline mix uses, the acceptance reading will be taken from the mainline portion. A typical lot will have 25 acceptance readings and 25 quality control readings. Record the location and mix use of each reading taken.

The NDT density readings will be entered into an approved DOTD software. The off-set value determined during validation will be applied in the software and reported. All result determination shall be completed within 1 calendar day. Differences between the Contractor's quality control and the Department's quality assurance density results will be considered acceptable if within ± 1.3%.

One destructive field core will be cut from the roadway every lot for offset verification. The location will be determined randomly by DOTD.

502.11.2.4 Disputed NDT Device Readings: In the event of a questionable NDT device reading, a core will be extracted from the center location of the 5 readings. The core density will replace that NDT device reading for determination of pay. If the core density is found to be unacceptable, the roadway inspector will isolate the questionable section with the NDT device. Corrective action or reduction in pay may be associated with the section.