

Nuclear Gauge Certification Workbook

Certified Inspector
Training Program

Nuclear Gauge Certification Workbook

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NUCLEAR GAUGE CERTIFICATION CIT PROGRAM

Written Test: Open book – 50 multiple choice questions

Grading: Must score at least 70% or better on the written exam. Failure on any part of the written exam requires retaking the entire exam.

Must pass all performance exam sections. Failure of three or less performance subtest requires retest on only the subtest(s) failed. Failure of four or more subtests of the performance exam requires retest on the entire performance exam.

Exam Results: Exams will be graded in two to three weeks. Exam results are emailed to the student. Exam results are not given over the phone.

Exam Re-takes: Students who need to re-take either the written and/or performance exam need to register to do so. The re-take registration form can be found on the CIT website at www.citksu.com.

To be certified: Students must successfully pass the written exam and the performance exam. The student will be emailed a certification card and letter.

Reasons for Certified Inspector Training (CIT) Training Program

Overview

The Kansas Department of Transportation (KDOT) has established this training program to educate, test and certify those individuals responsible for performing inspection and testing functions on KDOT construction projects. KDOT's Bureau of Construction and Materials has responsibility for the establishment and administration of the materials portion of the KDOT's Quality Control/Quality Assurance (QC/QA) Program. The Bureau develops standards and specifications for materials, establishes sampling procedures and frequencies, and test procedures used in the laboratory and the field in order to assure compliance with specifications. It performs materials testing to assist each of the six KDOT districts in administering quality assurance functions of the QC/QA Program. Such testing includes tests on materials purchased by contractors or the State for use in maintenance or construction activities. The Bureau also conducts tests on soils, concrete, bituminous mixtures and numerous other specialized materials, the results of which are used by others for a variety of reasons.

Quality control and quality assurance activities involve the routine sampling, testing and analysis of various materials to determine the quality of a given product and to attain a quality product. The goal of the Certified Inspection and Testing Training Program (CIT²) is to provide persons engaged in the inspection and/or testing of KDOT construction projects specific training in, but not limited to, soils, aggregates, and concrete and/or asphalt disciplines.

Each student is required to demonstrate specific abilities as defined by the training modules described in the CIT² manual. The manual can be found online at: https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burMatrRes/Documents/CIT_Manual_2019.pdf

Federal Funding

On projects involving federal funds, KDOT must certify to the Federal Highway Administration as to the quality of each type of material used on each project before the State is completely reimbursed by the federal government.

The certification and training requirements contained in this manual are intended to comply with the requirements of 23 CFR Part 637 which states, "After June 29, 2000, all sampling and testing data to be used in the acceptance decision or the IA (Independent Assurance) program shall be executed by qualified sampling and testing personnel."

Reasons for Quality Control/Quality Assurance

Inspectors fulfill a very important job on any project—they safeguard the public interest in a number of ways.

The primary reason for materials inspection, sampling and testing requirements is to verify that all materials incorporated into the work will meet the requirements of the contract documents, including the plans, specifications, and special provisions.

Plans and specifications are prepared to require the use of certain specific materials known or expected to perform satisfactorily with minimum maintenance throughout the life of the facility or infrastructure project. Any material that deviates appreciably from the specifications requirements will not perform as expected and, in all probability, will shorten the useful life of the facility or add unexpected costs in maintenance. Because there are limited dollars available for transportation infrastructure, the useful life and long-term maintenance costs of every project are critical considerations.

Secondly, all contractors bidding or furnishing materials to a project should be treated equally. That is, the contract documents provide a fair and uniform basis for bidding because they define the requirements to be met—ideally with the least possible difference of interpretation. The contractor commits to furnish materials and complete work that will equal or exceed such requirements. For this reason it is essential that quality assurance be correctly understood and applied uniformly by engineers and inspectors from project-to-project so that all contractors and suppliers are treated alike.

Thirdly, the expenditure of public funds must be documented to substantiate whether taxpayers actually received the quantity and quality of materials specified in exchange for tax dollars spent. Whether or not to pay the costs invoiced by contractors is a decision which relies heavily upon inspection reports and test results. In a fundamental way, inspectors play a key role in serving the public—to justify the expenditure of public monies and the acceptance of any contractor's work. Through the work of knowledgeable, competent and skilled inspectors, KDOT can verify and confirm whether or not the contractor has fulfilled its obligations to build the project as intended.

Finally, the specification requirements for materials are constantly evolving, based on new developments, past performance of material in the field, research and technological innovations. Accurate recordkeeping of materials and test results using consistent inspection practices provides a basis to compare results over time—an indispensable advantage for meaningful research. Data properly collected and recorded by inspectors can confirm whether or not changes in material specifications and testing requirements have, in fact, resulted in a better product, state-wide or in a particular location or application.

All inspectors should review the applicable clauses of the Standard Specifications at regular intervals to refresh their understanding of material and testing requirements.

Disclaimers

1. Radiation Safety Training is a prerequisite for this school.
2. This class predominantly demonstrates test procedures using the Troxler Electronics Laboratories, Inc. gauges. It is not the intent of this class to preclude the use of nuclear gauges from other manufacturers.
3. This class also addresses specific license mandates that KDOT personnel must follow. Correct safety precautions are always necessary when dealing with nuclear gauges.
4. It is not the intent of this class to fully address the test procedures and it is fully assumed that proper training has already been established prior to permitting operation of the gauge.

DAILY STANDARD COUNT

- Turn gauge on before leaving for project.
- Gauge has time for self-test.
- Gauge has warm-up period.

- Standard count can be taken at project without delay.

DAILY STANDARD COUNT

- Place standard block on flat surface at least 3 m (10 ft.) from any building/structure.

- Minimum of 10 m (30 ft.) from any other radioactive source.

DAILY STANDARD COUNT

- SURFACE
 - Asphalt
 - Concrete
 - Compacted Aggregate
 - Similar surface with density of at least 100 lb/ft³ (1600 kg/m³)

DAILY STANDARD COUNT

- FORBIDDEN SURFACES
 - Tailgates
 - Tabletops
 - Other machinery

DAILY STANDARD COUNT

- DO NOT INTERCHANGE STANDARD BLOCKS

DAILY STANDARD COUNT

- Properly set the gauge on the standard block.
- Ensure that the block top and gauge base are clean and smooth for good surface to surface contact.
- Continue by following instructions for make and model you are using.

DAILY STANDARD COUNT

- Standard Counts are to be taken **daily** regardless of make/model.
- Reason: This is to compensate for the continual decay of the radioactive sources.

5.8.2. INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES

The following establishes a method for verifying whether a nuclear density gauge is properly operating as established in **Appendix C**. It can also be a check to determine if the operator understands proper procedures for running the nuclear gauge.

1. GENERAL OVERVIEW

Nuclear gauge operators are to demonstrate proficiency in operating the gauge *at the project*. This will represent the Independent Assurance Witness (ASW) portion of the program. The focus of this section is to determine if the nuclear gauge can function properly. If more than one type of nuclear gauge (different series or manufacture) might be used during the course of the project, then each gauge is to be checked by this procedure. Properly warm up the gauge and establish the standard count as outlined under **Section 2. NUCLEAR GAUGE**. Turn off all offsets and correction factors (see **Section 3. OPERATOR**). Verify the nuclear gauge by placing it on the KDOT District's Validator™ (or Validator II™ when checking the 3450 or 4640 gauge) and establish the density of the block by taking 1 four-minute count.

If the gauge value is within the quantity established in **Appendix C**, when on the KDOT District's Validator™ or Validator II™, then the gauge can be used on the project. If not, then run a stability and drift test. If the gauge passes the stability and drift test, as outlined in **Section 2. NUCLEAR GAUGE**, then the gauge can be used on the project. If not, the gauge cannot be used on a KDOT project until the above requirements are met. Provide proof to the district representative that the problem has been corrected (i.e. new calibration with appropriate papers).

2. NUCLEAR GAUGE

2.1. GENERAL.

The nuclear gauge is to receive a multi-block calibration and a verification annually. Present copies of the previous two calibration papers to the district representative at the time of the Independent Assurance Replicate (ASR) check. Calibration papers are to be checked at the start of a project. Include yearly Calibration Papers in the QC/QA project's Quality Manual when applicable.

2.2. CALIBRATION OF NUCLEAR GAUGE.

As a minimum, the nuclear gauge must be calibrated by a Qualified Service Center for a full multi-block calibration on an annual basis. The technician performing the gauge calibration must have a current certificate in moisture density gauge calibration from a gauge manufacturer. The gauge must be disassembled, cleaned and lubricated prior to the calibration. Provide a copy of the gauge calibration documents to the district representative at the time of the ASR check.

2.3. VERIFICATION OF NUCLEAR GAUGE.

At least once a year, the nuclear gauge must be verified by KDOT. Verify the nuclear gauge by placing it on the KDOT District's Validator™ (or Validator II™ when checking the 3450 or 4640 gauge). Follow the procedures outlined in **Section 1. GENERAL OVERVIEW**. The Validator™ and Validator II™ blocks shall be calibrated at least once every five years. Maintain copies of the current Validator™ and Validator II™ calibrations at the District Office.

2.4. PROPER WARM-UP.

The gauge should be properly warmed up before starting any check. For the Troxler units, this means a minimum of 10 minutes. This permits the electronics to warm up to operating temperatures. If this step is not permitted the counts given can be significantly altered.

2.5. STABILITY AND DRIFT TEST.

Perform a stability and drift test on the gauge when the gauge fails the IA check. Any time the nuclear gauge readings are “suspect”, perform the STAT TEST (or stability test) to validate the normal operation of the gauge. The stability test requires the gauge to take 20 one-minute counts.

Perform the drift test 2 to 3 hours after the stability test to determine if the gauge reading “drifts” between tests. The drift test consists of 5 four-minute counts. It is highly recommended that the gauge not be moved from the block after taking the stability test and prior to taking the drift test.

Check the manufacturer’s manual for specifics on the results to be obtained. Contact the Materials Quality Control Engineer at the Materials and Research Center for assistance. For Troxler gauges, use the following table for acceptable limit results:

TROXLER GAUGE SERIES	Stability (STAT) Test*	Drift Test
3411-B and 3440	0.17 to 0.33 – acceptable <0.12 or >0.40 - unacceptable	Density: <0.5% Moisture: < 1.0%
4640-B	0.25 to 0.45	System 1 (Drift A): 0.50% System 2 (Drift B): 0.80%

* For the 3411-B and 3440, the numbers falling between acceptable and unacceptable should be considered carefully prior to acceptance/unacceptance. The 4640-B is considered to be unstable if the ratios are outside these limits for two out of three stat tests.

2.6. STANDARD COUNTS.

Take a standard count on a surface with 100 lb/ft³ (1600 kg/m³) or better. **DO NOT perform the standard count on the Validator.** Perform the stability and drift test prior to taking the standard count.

2.7. PASS/FAIL OF STABILITY AND DRIFT.

If the gauge fails the stability and drift test as defined in the manufacturer’s manual, then see **Section 1. GENERAL OVERVIEW** and consult the manufacturer (if KDOT gauge, call Materials Quality Control Engineer). If the gauge passes the stability but fails the drift, one alternative is to have the operator take new standard counts twice each day. Once when the operator begins in the morning and another in the early afternoon. All standard counts are to be recorded and monitored. As always, pay attention to your immediate surroundings when operating a nuclear gauge.

3. OPERATOR

The operator is to demonstrate understanding of the gauge's fundamental operations, which include the following:

1. Gauge turned on and permitted proper warm up time? _____
2. Set up, establish, and record a standard count? _____
3. Maintained a minimum of 3 ft (1 m) distance from gauge when in operation? _____
4. Verified all offsets and correction factors were turned off? _____
5. Properly seated gauge on concrete block? _____
6. Probe securely placed in the backscatter mode?
(verified the latch is properly seated in the notch) _____
7. Gauge permitted to determine density and results recorded? _____
8. Were there any vehicles within 10 ft (3 m)? YES / NO
9. Were there any nuclear gauges within 30 ft (10 m) YES / NO
10. What was the density determined? _____ lb/ft³ or kg/m³

DISTRICT 1 2 3 4 5 6

COMMENTS: _____

OPERATOR'S NAME: _____
WORKS FOR: _____
DATE: _____

The checklist represents the minimum an operator should know. A knowledgeable operator should provide new operators guidance. New operators are encouraged to take the gauge out and record a multitude of numbers in a single location with slight variations to the positioning of the base. This will give the operator a better understanding of the gauges' precision and how to optimize seating the gauge to the surface when such conditions apply.

5.9.32 METHOD OF TEST FOR DENSITY OF COMPACTED ASPHALT MIXTURES BY NUCLEAR METHOD (Kansas Test Method KT-32)

1. SCOPE

This method of test covers the procedure for measuring the “in-place” density of compacted asphalt materials by attenuation of gamma radiation. The intensity of the radiation detected is dependent in part on the density of the material being tested. **Gauge calibration shall follow Section 5.8.2. of this manual INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated-annually.

The equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken. (For KDOT field personnel only: Refer to Standard Operating Manual No. 1.13.2.).

2. REFERENCED DOCUMENTS

2.1. KT-14; Marshall Test of Bituminous Mixes

2.2. KT-15; Bulk Specific Gravity and Unit Weight of Compacted Hot Mix Asphalt (HMA)

2.3. KT-39; Theoretical Maximum Specific Gravity of Asphalt Paving Mixtures

2.4. Section 5.2.2.2.; Random Sampling

3. APPARATUS

NOTE: Check gauge to verify it is in asphalt mode.

3.1. Nuclear density gauge with supporting equipment including reference standard, survey meter, and instructional material.

3.2. Core drilling equipment capable of drilling a nominal 4 in (100 mm) diameter core.

3.3. Standardization.

3.3.1. Standardization of the nuclear gauge on a reference standard block is required at the start of each day’s use and when test measurements are suspect.

3.3.2. Warm up the nuclear gauge in accordance with the manufacturer’s recommendations.

3.4. Properly seat the nuclear gauge on the standard block. Take a four-minute reading on the reference standard. The density standard should be within 1% of the density for the previous day’s reading. If not,

repeat the standard count. The two numbers should now be within 1% of each other and within 2% of the density for the previous day's reading. If not, check the machine for malfunction.

4. TEST SITE SELECTION AND PREPARATION

4.1. Location of the test site should be on a random basis as described in **Section 5.2.2.2. RANDOM SAMPLING** of this manual. Regardless of the method of random selection chosen, it shall satisfy the requirement that any area of the surface shall have an equal chance of being sampled, except sampling shall not be conducted on sites closer than 1 ft (0.3 m) to an unconfined edge or vertical surface such as a raised edge of curb and gutter, etc. When the randomized selection method indicates a site within 1 ft (0.3 m) of an exposed edge or vertical surface, it is permissible to move the gauge transversely to clear the 1 ft (0.3 m) restriction. It is also permissible to determine an alternate location using the tables again.

4.2. Since the measured values of density are affected by the surface texture of the material immediately beneath the gauge, a flat surface should be tested for best results, both during calibration and density testing. If the mix has a coarse surface, it is likely that the results will vary widely.

4.3. It may be necessary to use a leveling sand of minus No. 30 (600 μm) material to obtain the best results with the density gauge. The leveling sand, as defined for this test, is minus No. 30 (600 μm) with no more than 20% represented by minus No. 100 (150 μm). It is recommended that the leveling sand material be from the same source as one of the individual aggregates in the mixture.

4.4. For HMA mix designs designated as A mixes, no sand is required. All other mix designs should be checked to determine if the leveling sand is needed before any field calibration of the nuclear density gauge is attempted. This is accomplished by doing the following:

4.4.1. Sit the gauge on a smooth level location and mark location with lumber crayon.

4.4.1.1. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

4.4.2. Take 5 one-minute readings with the density gauge, record wet density values, discard the single highest and lowest values, average the three remaining values, and record the average value.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

4.4.3. Inside the location marked with the lumber crayon (test site) thinly spread a sufficient amount of minus No. 30 (600 μm) material. Smooth and level the minus No. 30 (600 μm) material with the metal plate or a straight edge.

4.4.4. Place the density gauge on the test site after the placement of minus No. 30 (600 μm) material and take another density reading. Take care to use the same count time and location of source rod. Record wet density information obtained. It is recommended that this process be completed at three locations.

4.4.5. After the information has been obtained, determine the need for the minus No. 30 (600 μm) material leveling sand. Use the leveling sand if an increase of 1 lb/ft^3 (16 kg/m^3) or more is noted. If the leveling sand demonstrates a decrease in density, then the leveling sand is not beneficial and should not be used. An example of this calculation is as follows:

TEST SITE LOCATION	TEST SITE DENSITY lb/ft^3 (kg/m^3)	TEST SITE DENSITY WITH LEVELING SAND lb/ft^3 (kg/m^3)	DIFFERENCE lb/ft^3 (kg/m^3)
1	138.45 (2215)	139.50 (2232)	+1.05 (17)
2	140.35 (2246)	141.60 (2266)	+1.25 (20)
3	141.95 (2271)	143.06 (2289)	+1.11 (18)

NOTE: Density readings in above example are the average 3 one-minute readings (see **Section 4.4.2.** of this test method).

The difference in the example shows an increase in the density of more than 1 lb/ft^3 (16 kg/m^3) when the leveling sand is used. If it is determined that leveling sand will be used during the calibration process of the nuclear gauge then it is required that leveling sand be used during in-place density testing of the compacted asphalt.

5. CALIBRATION CURVE ADJUSTMENT

5.1. The manufacturer’s calibration curve may require adjustment for chemical composition or density. Examination to determine the need for such adjustment should be made whenever a change is made in either the material to be tested or testing equipment. This test is generally conducted by comparing nuclear gauge to core density values for four or more random locations. The difference between the two average density values are used to determine the correction factor (d_b) in **Section 7.6.1.1.** of this test method.

6. CALIBRATION LOCATIONS

6.1. For rural areas: Select locations starting after the second truck load. Each transverse and longitudinal random location shall fall within every other truck load.

6.2. For urban areas: If the asphalt mix quantities are large enough, use the rural criteria. If not, then decide if coring alone is a more feasible approach; or use best judgment to get a representative calibration for the nuclear gauge.

7. CALIBRATION PROCEDURE

7.1. Select a minimum of five locations that are typical of the asphalt mix being produced.

7.1.1. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

7.2. Take 5 one-minute readings in each location with the nuclear gauge in the backscatter or direct transmission (see **Section 8.2.** of this test method) position and mark the outline of the gauge in these locations. Record wet density values, discard the single highest and lowest values, average the three remaining values, and record the average value.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

7.3. Record the wet density (WD) directly from the nuclear gauge. Specific instructions on the individual gauges are in the manufacturer's instruction manual which is in the packet accompanying each gauge.

7.4. Take three cores from each of the marked areas. For lifts other than base course, it may be necessary to use a bond breaker.

7.5. Obtain the core density using **KT-15**.

7.6. Calculations

7.6.1. For each location subtract the average nuclear density from the average core density. Evaluate these differences for outliers by the "T" Statistic Test at the 95% confidence level. The following example illustrates the point:

7.6.1.1. "T" STATISTIC EXAMPLE:

CALCULATIONS FOR CALIBRATION OF NUCLEAR GAUGES ON ASPHALT PAVEMENT

n = Number of locations

d_i = Core Density – Nuclear Density

$d_b = \sum d_i / n$ = Correction Factor = Mean

s = Sample Standard Deviation

lb/ft³ (kg/m³) Nuclear = Nuclear Density, Average of 3 one-minute readings

lb/ft³ (kg/m³) Cores = Core Density, Average of three cores

Table 1
REJECTION QUOTIENTS ($T_{0.95}$)

n	$T_{0.95}$
2	-----
3	1.15
4	1.46
5	1.67
6	1.82
7	1.94
8	2.03
9	2.11
10	2.18

Assume cores and nuclear readings for the calibration are as follows. Calculate the difference (d_i) between cores and nuclear gauge readings.

SI EXAMPLE:

Location	Cores (kg/m ³)	Nuclear (kg/m ³)	Difference(d_i) (kg/m ³)
1	2176	2133	43
2	2187	2160	27
3	2176	2141	35
4	2197	2168	29
5	2185	2152	<u>33</u>
Total			+167

Calculate the correction factor (d_b)

$$d_b = \frac{\sum d_i}{n} = \frac{+167}{5} = +33.4$$

and standard deviation (s) between the cores and nuclear readings as follows:

Location	Cores	Nuclear	d_i	$d_i - d_b$	$(d_i - d_b)^2$
1	2176	2133	+43	+9.6	92.16
2	2187	2160	+27	-6.4	40.96
3	2176	2141	+35	+1.6	2.56
4	2197	2168	+29	-4.4	19.36
5	2185	2152	<u>+33</u>	<u>-0.4</u>	<u>0.16</u>
Total			+167		155.20

$$s = \sqrt{\frac{\sum (d_i - d_b)^2}{(n-1)}} = \sqrt{\frac{155.20}{4}} = 6.23$$

ENGLISH EXAMPLE:

Location	Cores (lb/ft ³)	Nuclear (lb/ft ³)	Difference(d _i) (lb/ft ³)
1	136.0	133.3	2.7
2	136.7	135.0	1.7
3	136.0	133.8	2.2
4	137.3	135.5	1.8
5	136.4	134.4	<u>2.0</u>
Total			10.4

Calculate the correction factor (d_b)

$$d_b = \frac{\sum d_i}{n} = \frac{+10.4}{5} = +2.1$$

and standard deviation (s) between the cores and nuclear gauge readings as follows:

Location	Cores	Nuclear	d _i	d _i -d _b	(d _i -d _b) ²
1	136.0	133.3	+2.7	+0.6	0.36
2	136.7	135.0	+1.7	-0.4	0.16
3	136.0	133.8	+2.2	+0.1	0.01
4	137.3	135.5	+1.8	-0.3	0.09
5	136.4	134.4	<u>+2.0</u>	<u>-0.1</u>	<u>0.01</u>
Total			+10.4		0.63

$$s = \sqrt{\frac{\sum (d_i - d_b)^2}{(n-1)}} = \sqrt{\frac{0.63}{4}} = 0.40$$

Application of the “T” test requires the following steps:

1. Arrange the deviations (d_i) in ascending order of magnitude.

(SI)	(ENGLISH)
d ₁ = 27	1.7
d ₂ = 29	1.8
d ₃ = 33	2.0
d ₄ = 35	2.2
d ₅ = 43	2.7

2. Calculate the difference between the questionable measurement (d₁ or d_n) and the mean (d_b). Then divide the deviation from the mean (d_b - d₁ or d_n - d_b) by the sample standard deviation (s), demonstrated by the

formula "T" (illustrated below). Thus, if the questionable measurement (the measurement demonstrating the greatest variance from the other measurements) is the first measurement (d_1) in the arranged set of results.

$$T = \frac{d_b - d_1}{s}$$

If the questionable measurement is the last measurement (d_n) in the arranged set of results.

$$T = \frac{d_n - d_b}{s}$$

3. If the "T" is equal to or greater than the $T_{0.95}$ value (for 95% confidence limits) for the number (n) of results considered (See Table 1) the questionable measurement may be rejected with 95% confidence that some definite error is involved in this measurement which was not involved in the other measurements of the set. For this example, the questionable measurement is d_5 because it demonstrates the largest spread from the other measurements.

$$T \text{ (SI)} = \frac{d_n - d_b}{s} = \frac{43 - 33.4}{6.23} = 1.54$$

$$T \text{ (ENGLISH)} = \frac{d_n - d_b}{s} = \frac{2.7 - 2.1}{0.40} = 1.50$$

For $n = 5$, $T = 1.67$ (Table 1). Calculated T is less than 1.67; therefore, this value is not rejected (not an outlier). If the T value had been equal to or greater than 1.67, discard the core results from this location. Recalculate **Section 7.6.1.1** of this test method using the remaining core results.

NOTE: When calibrating multiple gauges, if it becomes necessary to discard a location or locations because the location or locations failed either the standard deviation (s) or the "T" test, then the same location or locations **must** be discarded for all gauges being calibrated using these set of cored locations.

7.6.2. A minimum of four data points must pass the T-test in **Section 7.6.1** of this test method. The standard deviation (s) should be less than or equal to 2.0 lb/ft³ (32 kg/m³). If it is larger than 2.0 lb/ft³ (32 kg/m³), this calibration shall be discarded.

7.6.3. The correction factor (d_b) is applied to each nuclear density reading on the project to obtain a corrected nuclear density.

8. TEST PROCEDURE (HOT MIX)

8.1. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

8.1.1. Backscatter mode: Properly seat the gauge as stated in **Section 4.4.1** of this test method and expose the source by depressing the source rod (or handle) to the first stop. Take 5 one-minute readings

with the density gauge, record wet density values, discard the single highest and lowest values, average the three remaining values, and record the average value.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

8.2. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

8.2.1. Direct transmission mode: Create a hole 2" (50 mm) deeper than the thickness of the material being tested with the rod and hole forming device that is provided with the gauge. Lower the source rod into the hole to the predetermined depth.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

NOTE: Always double check to make sure the probe is fully seated in the appropriate notch. This should be confirmed in the safe, backscatter, or any direct transmission position.

9. TEST PROCEDURE (COLD RECYCLE)

9.1. Develop compaction growth curves (rolling sequence) for cold recycle material using the backscatter position. Compaction growth curves will help to determine optimum density of material for a given roller. Curves are developed by plotting the density of material against the accumulative roller passes (**D.O.T. FORM NO. 608 or 608M**).

NOTE: In determining data for compaction growth curves, it is not necessary to calibrate the gauge to the material. Also, a single one-minute count can be used to establish each point for the curve.

9.2. To determine in place density use either direct transmission or backscatter as approved by the district.

9.3. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

9.3.1. Take 5 one-minute readings with the density gauge, record wet density values, discard the single highest and lowest values, average the three remaining values, and record the average value.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

10. CALCULATIONS

10.1. Calculation methods applicable to the various gauge types are covered in the Manufacturer's Operating Manual which accompanies the gauge and are not reproduced in this procedure.

10.2. Wet density (WD) values, as determined by the method appropriate to the type of gauge and method of calibration shall be compared to the "Density Standard" for determination of Percent of the Standard and Percent of Voids.

10.3. Density Standards.

10.3.1. Density Standard for Nuclear Density shall be defined as the average value of the most recent three laboratory density determinations (Field Mold Density) as determined by **KT-14** and **KT-15** for Marshall mix designations. When fewer than three laboratory densities for the particular mix designation or revised asphalt content are available, the "Density Standard" shall be the average of those determinations made until a total of three may be averaged.

10.3.2. For Superpave mixes, the "Density Standard" is established with the use of the average daily G_{mm} value (**KT-39**) as outlined in the specifications.

10.4. Calculate the Wet Density (WD) value from the following:

10.4.1. Wet Density (WD) = indicated lb/ft^3 (kg/m^3) with the adjustment factor applied as determined in **Section 7. CALIBRATION PROCEDURE** of this test method.

10.5. Calculate the percent of standard from the following formula:

$$\text{Percent of Standard} = \frac{100 (\text{WD})}{\text{Density Standard}}$$

10.6. Calculate the percent voids from the following formula:

$$\text{Percent Voids} = 100 - \frac{100(\text{WD})}{\text{Density of Water}^d (G_{mm})}$$

Where: G_{mm} = Theoretical maximum specific gravity of the mixture (refer to **KT-39**).

NOTE: Density of water varies based on temperature. Determine the temperature and select the proper density for water (see **KT-15, Table 1**).

11. REPORT AND RECORD

11.1. Report and record as 0.1 lb/ft^3 (1 kg/m^3) or 0.01% of optimum density.

KANSAS DEPARTMENT OF TRANSPORTATION

APPROVED ROLLING PROCEDURE

Project _____ County _____ Lab. No. _____

Contractor _____ Field Engineer _____

Gauge Type _____ Number _____ Std. Count _____

Operator _____ Date _____ Mix Design No. _____

Mix Type _____ Thickness _____ Base _____ OR Surface _____

Weather _____

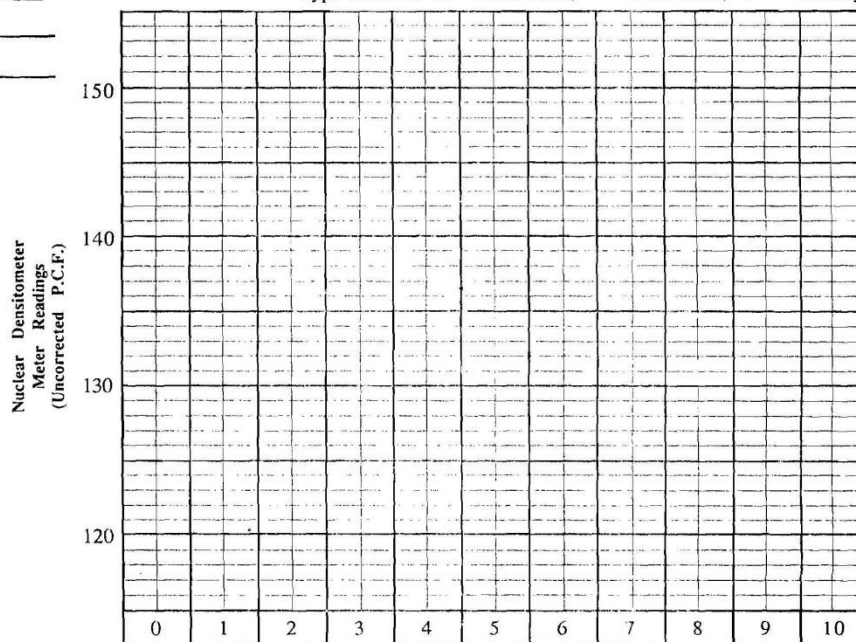
Description	Pass	0	1	2	3	4	5	6	7	8	9	10
	Roller #1											
	Roller #2											
	Roller #3											
	Temp											
	P.C.F.											
	Time											

V-Roller No. ___ No. ___

Type of Roller S - Static Steel, P - Pneumatic, V - Vibratory

Frequency(VPM) _____

Speed(FPM) _____



PASSES

Note: 1 Pass - 1 Time Over A Given Spot

Recom. Rolling Procedure _____

DISTRICT ENGINEER
FIELD ENGINEER
DISTRICT MATERIALS ENGINEER

District Materials Engineer

Date

DOT Form No. 608

KANSAS DEPARTMENT OF TRANSPORTATION

APPROVED ROLLING PROCEDURE

Project _____ County _____ Lab No. _____
 Contractor _____ Field Engineer _____
 Gauge Type _____ Number _____ Std. Count _____
 Operator _____ Date _____ Mix Design No. _____
 Mix Type _____ Thickness (mm) _____ Base _____ OR Surface _____
 Weather _____

Description	Pass	0	1	2	3	4	5	6	7	8	9	10
Roller #1												
Roller #2												
Roller #3												
Temp. (C)												
kg/m3												
Time												

V-Roller	No.	No.	2400	Type of Roller S-Static Steel, P-Pneumatic, V-Vibratory																
Frequency (VPM)	_____	_____																		
Speed (FPM)	_____	_____	2300																	
			2200																	
			2100																	
			2000																	
			1900																	
			1800																	
			1700																	
				0	1	2	3	4	5	6	7	8	9	10						

PASSES
 Note: 1 Pass - 1 Time Over A Given Spot
 Recom. Rolling Procedure _____

District Engineer
 Field Engineer
 District Materials Engineer

 District Materials Engineer

 Date

D.O.T. FORM NO. 608M

5.9.36 DENSITY OF FRESHLY MIXED CONCRETE IN BRIDGE DECK OVERLAYS BY NUCLEAR GAUGE (Kansas Test Method KT-36)

1. SCOPE

This method of test covers the procedure for determining the in-place density of freshly mixed concrete in bridge deck overlays using a nuclear density gauge. This method is applicable to all types of concrete. **Gauge calibration shall follow 5.8.2. of this manual INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated-annually.

The equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken. (For KDOT field personnel only: Refer to Standard Operating Manual No. 1.13.2.).

2. REFERENCED DOCUMENTS

2.1. KT-20; Weight Per Cubic Foot (Meter), Yield and Air Content (Gravimetric) of Freshly Mixed Concrete

3. APPARATUS

NOTE: Check gauge to verify it is in asphalt mode.

3.1. Nuclear density gauge with supporting equipment including reference standard, survey meter, and instructional material.

3.2. Frame to hold gauge at the concrete surface of the in-place material.

3.3. Shovel, trowels, wash bucket, tire brush, rags.

3.4. Tape measure.

3.5. Pachometer.

3.6. Depth Gauging Wire.

3.7. A supply of No. 30 (600 μm) sand screened from the fine aggregate in the mix or a pan and a No. 30 (600 μm) sieve.

3.8. Brush for cleaning up sand.

4. DAILY WARM UP AND CHECK

The nuclear gauge shall be turned on for warm-up and checked according to the manufacturer's instructions.

5. TEST PROCEDURE

Readings should be taken in a random manner unless there are sound reasons to relocate. Readings should not be taken closer than 1 ft (0.3 m) to a vertical surface.

5.1. Direct Transmission Readings

5.1.1. For uniformity, the gauge operator shall position the source rod so it is closest to the finish machine (point the gauge towards the placement of the concrete overlay).

5.1.2. Place the gauge on the surface and depress the probe to the appropriate depth, when exceeding 2 in (50 mm). On very stiff mixes, it may be necessary to make a hole in the fresh concrete with the 5/8 in (15 mm) graduated pin and hole-forming device furnished with the gauge. The alignment of the hole and the probe is greatly facilitated if the gauge is placed on the concrete surface first. The probe location will show on the fresh concrete as will the outline of the gauge. Take 5 one-minute readings, record wet density values, discard the single highest and lowest values, average the three remaining values, record the average value, and divide this average by the three point moving average of unit weight of fresh concrete.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

5.2. Backscatter Readings

5.2.1. Backscatter readings are required on overlays 2 in or less (50 mm or less) thick. In addition, the effect of the underlying layer on the readings needs to be taken into account. This is done as follows:

5.2.1.1. Obtain a supply of minus No. 30 (600 μm) sand.

5.2.1.2. Mark the location of the top reinforcing steel using a pachometer in at least three relatively smooth areas.

5.2.1.3. Place some sand in the area between the reinforcing steel and screed off the excess using a rule or other straight edge. The area covered by the sand should be slightly larger than the bottom of the nuclear gauge and should have all the surface voids filled with the fine sand. There should only be enough sand to fill the voids. Excessive quantities can be counterproductive.

5.2.1.4. For uniformity, the gauge operator shall position the source rod so it is closest to the finish machine (point the gauge towards the placement of the concrete overlay).

5.2.1.5. Place the gauge on the prepared area, lower the probe to the backscatter position, take 5 one-minute readings, record wet density values, discard the single highest and lowest values, average the three remaining values, record the average value.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

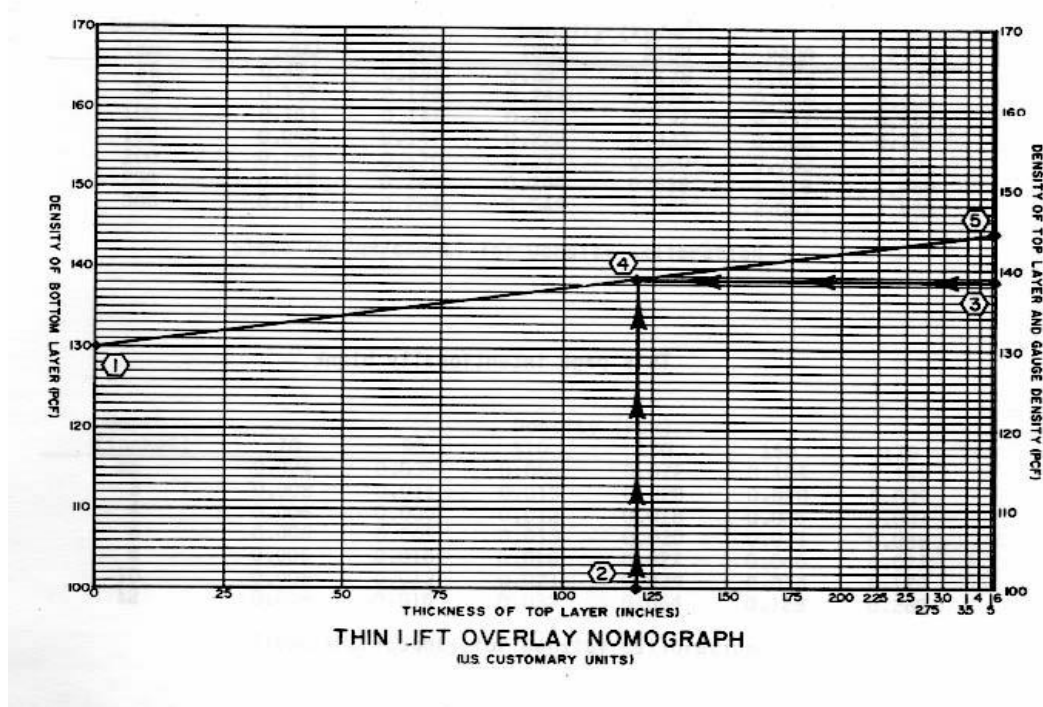
5.2.2. Repeat **Section 5.2.1.5** of this test method in at least two other locations. Average all of these for an average density of the underlying layer. Low readings originating from an air gap under the gauge should not be included in the average.

5.2.3. The nuclear readings on the overlay are corrected by using the formula in **Section 5.2.3.1.** or by using the nomograph and the procedure in the manufacturer's manual, as shown in the examples below:

****NOTICE****

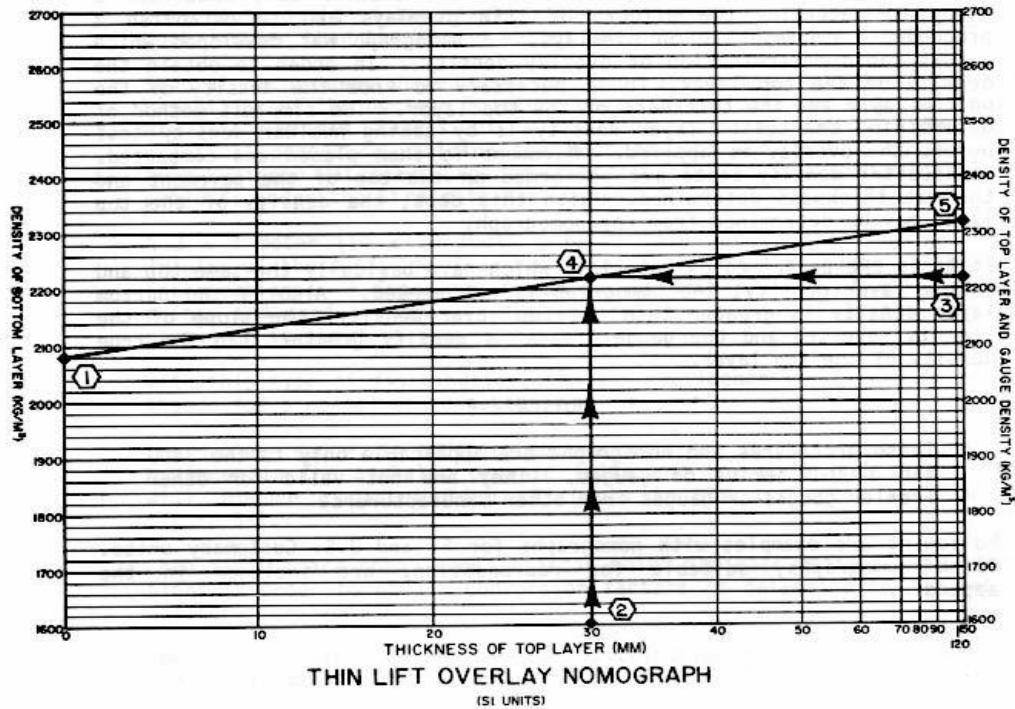
This procedure and nomograph are applicable only to the 3400 series gauge. It is not valid for other Troxler gauges or gauges from other manufacturers. The Troxler 3440 gauge contains software which can make the corrections described above within itself. Refer to operators manual.

IN ENGLISH UNITS



In this example, the bottom layer density (left scale) is 130 lb/ft³ with a mat of 1.2 inches thick overlaying it. A backscatter density test on the top of the mat (right scale) yielded a result of 138.5 lb/ft³. A line is then drawn from 130 lb/ft³ on the left scale through the intersection of 1.2 inches (bottom) and 138.5 lb/ft³ (right) and extended to the right. The correct density for the top layer is then read from the nomograph as 144.5 lb/ft³ on the right scale.

IN SI UNITS:



In this example, the bottom layer density (left scale) is 2080 kg/m³ with a mat of 30 mm thick overlaying it. A backscatter density test on the top of the mat (right scale) yielded a result of 2220 kg/m³. A line is then drawn from 2080 kg/m³ on the left scale through the intersection of 30 mm (bottom) and 2220 kg/m³ (right) and extended to the right. The correct density for the top layer is then read from the nomograph as 2320 kg/m³ on the right scale.

5.2.3.1. The following formula may be used to correct thin layer measurements of overlays of 1 to 3 inches (25 to 75 mm) in thickness when using Troxler 3401, 3411-B and 3430:

$$DT = \frac{DG - DB * K}{1 - K}$$

Where:

DT = Corrected overlay density

DG = Density read by gauge

DB = Bottom layer density

K = Effect of top layer thickness on the gauge (From Table 1 below)

Table 1

Thickness (inches)	Thickness (mm)	K	Thickness (inches)	Thickness (mm)	K
1.0	25	0.46152	2.1	53	0.14617
1.1	28	0.42042	2.2	56	0.12880
1.2	30	0.38235	2.3	58	0.11275
1.3	33	0.34710	2.4	61	0.09790
1.4	36	0.31462	2.5	63	0.08418
1.5	38	0.28454	2.6	66	0.07149
1.6	41	0.25673	2.7	69	0.05976
1.7	43	0.23102	2.8	71	0.04892
1.8	46	0.20725	2.9	74	0.03889
1.9	48	0.18527	3	76	0.02962
2.0	51	0.16495			

5.2.4. For uniformity, the gauge operator shall position the source rod so it is closest to the finish machine (point the gauge towards the placement of the concrete overlay).

5.2.5. Number of readings: Take 5 one-minute readings at a single location, record wet density values, discard the single highest and lowest values, average the three remaining values, record the average value, and divide this average by the three point moving average of unit weight of fresh concrete.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

6. CALCULATION

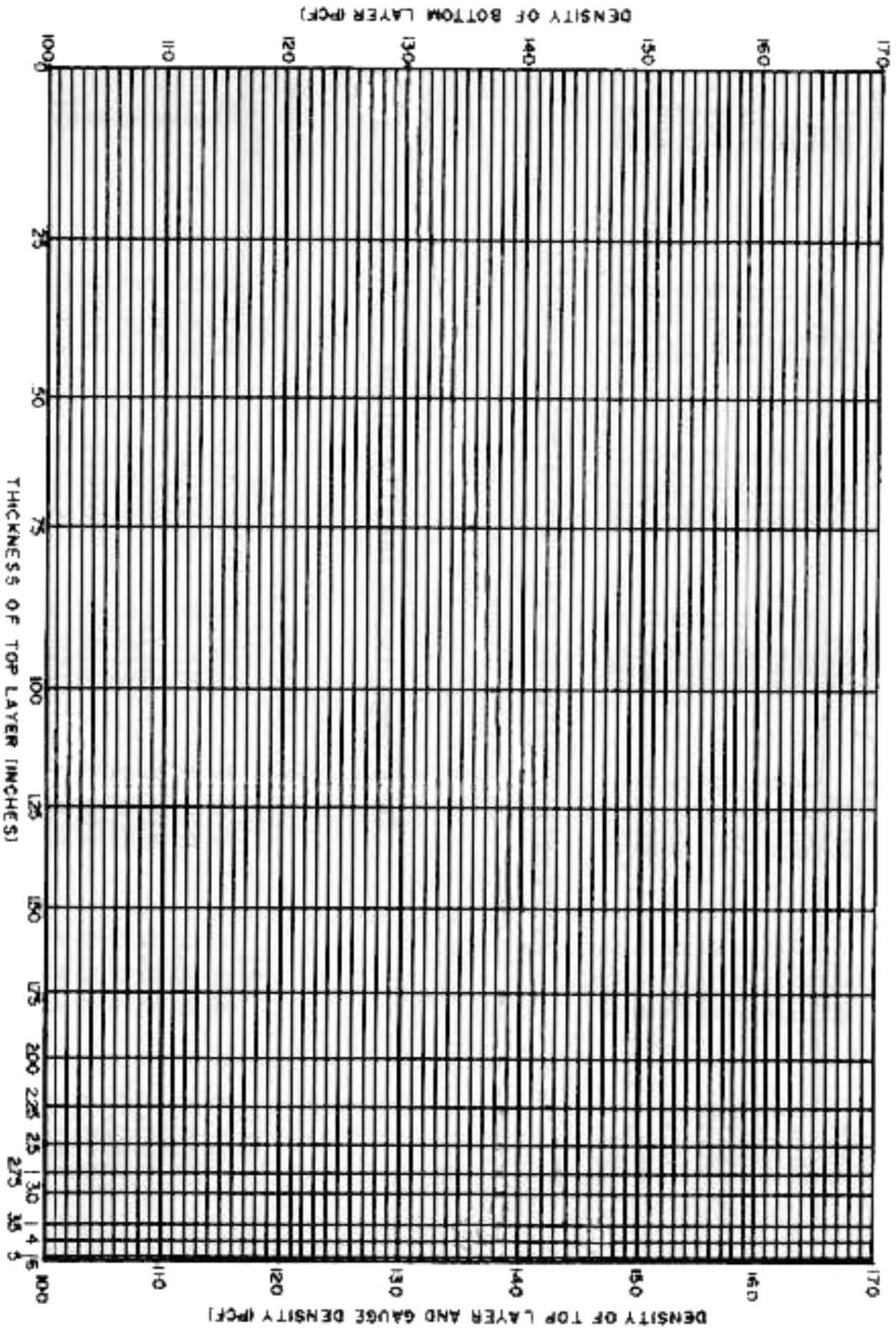
6.1. The average wet density reading is divided by the three point moving average of the unit weight of concrete and multiplied by 100 to obtain a percent density. When fewer than three unit weights are available, the “Density Standard” shall be the average of those determinations made until a total of three may be averaged.

$$\text{Percent of Standard} = \frac{100(\text{WD})}{\text{Density Standard}}$$

7. REPORT AND RECORD

7.1. Report and record wet density values as 0.1 lb/ft³ (1 kg/m³).

7.2. Report and record Percent of Standard Density to the nearest whole percent.



THIN LIFT OVERLAY NOMOGRAPH

(US CUSTOMARY UNITS)

KT-36 NOMOGRAPH

100 (WD)

DENSITY STANDARD = % OF STANDARD

5.9.38 DENSITY OF FRESHLY MIXED CONCRETE IN PAVEMENT BY NUCLEAR METHOD
(Kansas Test Method KT-38)

1. SCOPE

This method of test covers the procedure for determining the in-place density of freshly mixed concrete in pavements using nuclear density gauge. This method is applicable to all types of concrete. **KT-38** reflects testing procedures found in **ASTM C1040. Gauge calibration shall follow 5.8.2. INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated-annually.

The equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken (For KDOT field personnel only: Refer to Standard Operating Manual No. 1.13.2.).

2. REFERENCED DOCUMENTS

- 2.1.** KT-20; Weight Per Cubic Foot (Meter), Yield and Air Content (Gravimetric) of Freshly Mixed Concrete
- 2.2.** C1040; In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods

3. APPARATUS

NOTE: Check gauge to verify it is in asphalt mode.

3.1. Nuclear density gauge with supporting equipment including reference standard, survey meter, and instructional material.

4. DAILY WARM-UP CHECK

The nuclear gauge shall be turned on for warm-up and checked according to the manufacturer's instructions.

5. TEST PROCEDURE

5.1. For uniformity, the gauge operator shall position source rod so it is closest to the paving machine (point the gauge toward the concrete placement).

5.1.1. Transverse Profile of Densities: A transverse profile of wet densities shall be taken to evaluate the effectiveness of the consolidation system. This profile is developed by taking a single one-minute density reading in each vibrator path and in each gap between two vibrators across the entire placement width. Although not all readings can be obtained at one station, an effort should be made to develop the profile in as short a time as possible. A complete profile needs to be run each time a change is made in the placement machine which could affect consolidation.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

5.2. For uniformity, the gauge operator shall position source rod so it is closest to the paving machine (point the gauge toward the concrete placement).

5.2.1. In-Place Concrete Densities: The daily wet density readings should be taken in both the vibrator paths and the gaps between vibrators to verify the density profile as well as document the percent of required consolidation taking place. Take 5 one-minute readings, record wet density values, discard the single highest and lowest values, average the three remaining values, and record the average value. These readings should be taken no closer than 1 ft (0.3 m) to a vertical edge nor within 2 ft (0.6 m) of a dowel basket assembly.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

5.3. Place the gauge on the surface and depress the probe to the appropriate depth, normally 8 in (200 mm). After the readings are taken, lift the gauge from the concrete by the case and clean the probe before restoring the probe to its safe position.

6. CALCULATION

6.1. The wet density (WD) is divided by the three point moving average of the consolidated unit weight of concrete, **KT-20**, and multiplied by 100 to obtain a percent density. When fewer than three consolidated unit weights of concrete are available, the “standard density” shall be the average of those determinations made until a total of three may be averaged.

$$\text{Percent of Consolidation} = \frac{100(\text{WD})}{\text{Density Standard}}$$

NOTE: For concrete, record the WD reading from the nuclear density gauge.

7. REPORT AND RECORD

7.1. Report and record wet density values as 0.1 lb/ft³ (1 kg/m³).

7.2. Report and record Percent of Standard Density to the nearest whole percent.

5.9.41 DETERMINATION OF DENSITY AND MOISTURE CONTENT OF PORTLAND CEMENT TREATED BASES, AGGREGATE BASES AND AGGREGATE SHOULDERS BY NUCLEAR METHOD (Kansas test Method KT-41)

1. SCOPE

This method of test covers the procedure for calibrating the nuclear gauge and determining density and moisture in Portland Cement treated bases, aggregate bases and aggregate shoulders. **Gauge calibration shall follow 5.8.2. INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated annually. **KT-41** reflects procedures found in **ASTM C1040**.

The equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken. (For KDOT field personnel only: Refer to Standard Operating Manual No. 1.13.2.).

2. REFERENCED DOCUMENTS

2.1. Part V, 5.9.; Sampling and Test Methods Foreword

2.2. KT-11; Moisture Tests, Section 4. Constant Mass Method

2.3. KT-13; Field Density Tests of Soils, Treated Base Courses, and Water Bound Base Courses

2.4. KT-32; Method of Test for Density of Compacted Asphalt Mixtures by Nuclear Method

2.5. KT-43; Moisture Content of Asphalt Mixtures or Mineral Aggregates - Microwave Oven Method

2.6. C1040; In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods

3. APPARATUS

NOTE: Check gauge to verify it is in soil mode.

3.1. Nuclear moisture/density gauge with supporting equipment including reference standard, survey meter, and instructional material.

3.2. KDOT Validator: Device to establish a wet density field correction factor for the nuclear gauge. Each Validator has a certified block density.

3.3. A supply of minus No. 30 (600 μ m) sand with no more than 20% represented by minus No. 100 (150 μ m).

3.4. Brush for cleaning up the fine sand.

3.5. The balance shall be readable to 0.01 lb (5 g) and sensitive to 0.005 lb (1 g) and conform to the requirements of **Part V, Section 5.9; Sampling and Test Methods Foreword** of this manual for the class of general purpose balance required for the principal sample mass of the sample being tested.

3.6. Shelter to protect the balance from wind currents and the sample from exposure to the sun or wind.

3.7. Oven capable of maintaining a constant temperature of approximately 230°F (110°C). If available, a microwave oven as described in **KT-43** may be used.

3.8. Miscellaneous equipment including standard drying pans, trowel, large spoon, hammer, square point shovel, and air tight containers.

4. NUCLEAR GAUGE WARM UP AND CHECK

The nuclear gauge shall be turned on for warm-up and checked according to the manufacturer's instructions.

5. TEST SITE SELECTION AND PREPERATION

Test site shall be selected as outlined in **KT-32, section 4.1**. Leveling sand may be needed.

6. VALIDATOR CORRECTION FACTOR

6.1. Use the KDOT Validator to determine the wet density field correction factor for density in the following manner:

6.1.1. Place the gauge on the Validator at the depth to be used on the project.

6.1.2. Take 5 one-minute readings, discard the single highest and lowest values, record the three remaining wet density values.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

6.1.3. Determine the average difference (field density correction factor) using **Section 9.1** of this test method.

6.1.4. Use this correction factor to determine the final wet density reading for each test site.

7. PERCENT MOISTURE CORRECTION FACTOR

7.1. Use **KT-11, Section 4, Constant Mass Method**, to determine the percent moisture correction factor.

7.2. Conduct a minimum of seven tests. Compute the correction factor for each test. The sample standard deviation (*s*) for the percent moisture content correction factors must be less than 1%. If the above criteria is met, use the average correction factor computed. If the *s* criteria is not met, start over again with seven new tests.

NOTE: When calibrating multiple gauges, if it becomes necessary to discard a location or locations because the location or locations failed the standard deviation (*s*), then the same location or locations **must** be discarded for all gauges being calibrated using these set of cored locations.

NOTE: A test represents 5 one-minute Wet Density (WD) and Percent Moisture (%M) readings from the gauge. Record the lb/ft³ (kg/m³) on Wet Density (WD) and Percent Moisture (%M) for each reading. Discard the single highest and lowest wet density values along with their accompanying percent moisture values, average the three remaining percent moisture values, and record the average value.

7.3. Dry the material removed from the test hole to a constant weight at approximately 230°F (110°C). The material shall be dried the same day it is cored. Record the dry weight and calculate the percent moisture.

8. TEST PROCEDURE

8.1. Location of the test site should be on a random basis. Any of several methods may be used, however, the use of a set of Random Number Tables (see **Section 5.2.2.2. Random Sampling** of this manual) is recommended. Regardless of the method selection chosen, it shall satisfy the requirement that any area of the surface shall have an equal chance of being sampled. Sampling shall not be conducted on sites closer than 1.0 ft (0.3 m) to an unconfined edge or vertical surface such as a raised edge of curb and gutter, etc. When the randomized selection method indicates a site within 1 ft (0.3 m) of an exposed edge or vertical surface, it is permissible to move the gauge transversely to clear the 1 ft (0.3 m) restriction. It is also permissible to determine an alternate location using the table again.

8.2. Since the measured values of density are affected by the surface conformation of the material immediately beneath the gauge, a flat surface should be tested for best results, both during calibration and density testing. If the mix has a coarse surface, it is likely that the results will vary widely. Calibration and testing should be done with leveling sand immediately beneath the gauge. Spread thinly a sufficient amount of minus No. 30 (600 µm) sand on the test site and smooth with the metal plate or a straight edge to obtain a suitable surface with a minimum amount of the sand.

8.3. For uniformity, the gauge operator shall position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

8.4. After the site selection has been made, a vertical hole is made 2 in (50 mm) deeper than the thickness of the material with the rod and plate provided with the gauge. If the thickness of the material exceeds the depth capability of the gauge, then a hole is made 2 in (50 mm) deeper than the gauge's maximum depth. The same hole depth used for calibration is to be used for normal testing. Set the probe to maximum depth or at a depth equal to the plan thickness, whichever is less. Wet density and percent moisture readings can now be taken using 5 one-minute counts, discard the single highest and lowest wet density values along with their accompanying percent moisture values, average the three remaining wet density values and record, and average the three remaining percent moisture values and record.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

9. CALCULATIONS

9.1. Compute Field Density Correction Factor and Corrected Wet Density.

Individual Correction Factor = Validator – Nuclear Gauge

$$\text{Avg. Correction Factor} = \frac{\sum 3 \text{ Individual Correction Factors}}{3}$$

$$WD = WD_i + \text{Avg. Correction Factor}$$

Where: WD_i = initial gauge reading at test site
 Validator = certified block density

9.2. Compute Percent Moisture Content Correction Factor

9.2.1. $U_i = (w - X)$

Where: w = moisture content, percent (see **KT-11, Section 5.1.** for determination of w)
 X = Nuclear Gauge moisture content, percent
 U_i = Individual difference between w and X

9.2.2. Average percent moisture content correction factor (U).

$$U = \frac{\sum U_i}{n}$$

9.3. Sample standard deviation (s) (see **KT-32, Section 7.6.1.1.** for more detail):

$$s = \sqrt{\frac{\sum (d_i - d_b)^2}{n - 1}}$$

Where: d_i = Individual difference (U_i)
 d_b = Average difference (U)

9.4. Corrected Percent Moisture Content, (%M)

$$\%M = (X + U)$$

9.5. Dry Density, lb/ft³ (kg/m³), (DD)

$$DD = \frac{WD}{\left(1 + \frac{\%M}{100}\right)}$$

Where: WD = Nuclear Gauge Wet Density, lb/ft³ (kg/m³)

9.6. Percent of Proctor = $\frac{100 (WD)}{\text{Standard Proctor}}$ or $\frac{100 (DD)}{\text{Standard Proctor}}$

10. REPORT AND RECORD

10.1. Report and record as 0.1 lb/ft³ (1 kg/m³) or 0.1% of optimum density.

5.9.51 FIELD DENSITY AND MOISTURE TESTS OF SOILS BY NUCLEAR GAUGE

(Kansas Test Method KT-51)

1. SCOPE

This method of test covers the procedure for measuring the “in-place” density and moisture of soils by the attenuation of gamma and neutron radiation. The intensity of the radiation detected is dependent in part on the density of the material being tested. It should be recognized that the density and moisture determined by this method is not necessarily the average value within the measured volume at any one location. **Gauge calibration shall follow section 5.8.2 of test method, INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated-annually. **KT-51** reflects procedures found in **AASHTO T 310**.

The equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken. (For KDOT field personnel only; Refer to Standard Operating Manual No. 1.13.2).

2. REFERENCED DOCUMENTS

2.1. KT-11; Moisture Tests

2.2. AASHTO T 310: In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Method (Shallow Depth)

2.3. KT-41; Determination of Density and Moisture Content of Portland Cement Treated Bases, Aggregate Bases and Aggregate Shoulders by Nuclear Method

3. APPARATUS

NOTE: Check gauge to verify it is in soil mode.

3.1. General.

3.1.1. Probe: Either the gamma source or the gamma detector shall be housed in a probe for insertion into a preformed hole of the material to be tested. The probe shall be marked in increments of 2 in (50 mm) for tests with probe depths from 2 in (50 mm) to a maximum of 12 in (300 mm). The probe shall be mechanically held in place when it is manually moved to the desired depth.

3.1.2. Housing: The source, detector, readout device, probe, and power supply shall be in housings of rugged construction that are moisture and dust proof.

3.1.3. Guide: A guide used for the hole forming device to make a hole, normal to the prepared surface.

3.1.4. Hole-forming Device: An auger, pin, or similar device for forming a hole in the soil to accommodate the probe. The hole-forming device shall have a nominal diameter equal to or up to 1/8 in (3 mm) greater than the probe diameter.

3.1.5. Extraction tool.

3.1.6. Miscellaneous equipment including shovel or auger, drying pans, and air tight containers.

3.2. Standardization.

3.2.1. Standardization of the nuclear gauge on a reference standard block is required at the start of each day's use and when test measurements are suspect.

3.2.2. Warm up the nuclear gauge in accordance with the manufacturer's recommendations.

4. DETERMINING MOISTURE CORRECTION FACTOR USING THE NUCLEAR GAUGE

NOTE: If **KT-11** is used for moisture determination instead of the nuclear gauge, then skip **Section 4.** of this test method, Determining Moisture Correction Factor Using The Nuclear Gauge.

4.1. For uniformity, the gauge operator shall position the source rod so it is closest to the compaction equipment (point the gauge towards the roller).

4.2. A Determination* by the nuclear method is to be compared with moisture quantities described under **KT-11, Section 4.0., CONSTANT MASS METHOD.** Moisture samples shall be extracted from the same location the nuclear gauge readings are taken. At least six separate locations are required. Discard the location(s) with the greatest deviation to leave five pair of samples for analysis. Prepare the test site and proceed as stated in **Section 5. TEST PROCEDURE** of this test method.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

* A determination represents 5 one-minute Wet Density (WD) and Percent Moisture (%M) readings from the gauge. Record the lb/ft³ (kg/m³) on Wet Density (WD) and Percent Moisture (%M) for each reading. Discard the single highest and lowest wet density values along with their accompanying percent moisture values, average the three remaining percent moisture values, and record the average value.

4.3. Compare the six or more sample pairs of oven dry and nuclear gauge results from the locations listed above in **Section 4.2** of this test method. Discard the sample pair(s) that deviate the greatest from the remaining five. Oven dry samples are to be at least 1,000 g and are to be taken under the center of the gauge to a depth of 6 to 8 in (150 to 200 mm). Nuclear tests are to be taken without any type of internally applied corrections.

4.4. Prepare a chart of sample pairs as shown below:

Sample No.	(%M OD)	(%M NUCLEAR)	Moisture Difference (%M OD - %M NUCLEAR)
1	4.5	8.6	-4.1
2	4.0	5.9	-1.9
3	7.2	9.7	-2.5
4	6.7	8.6	-1.9
5 *	3.9 *	9.5 *	-5.6 *
6	<u>4.7</u>	<u>8.6</u>	<u>-3.9</u>
Average	5.4	8.3	-2.9

NOTE: "*" represents the discarded sample pair.

NOTE: If the Average Moisture Difference exceeds $\pm 1\%$, a Moisture Correction Factor will be required for that soil type.

4.5. To determine the correction factor, calculate the average moisture difference value and proceed as follows:

4.5.1. Calculate the Moisture Correction Factor using the average difference values, as follows:

$$\text{Moisture Corr. Factor} = \frac{100 (\text{Avg. Oven \%M} - \text{Avg. \%M Gauge})}{100 + \text{Avg. \%M Gauge}}$$

In the example above, the moisture correction would be as follows:

$$\text{Moisture Corr. Factor} = \frac{100 (5.4 - 8.3)}{100 + 8.3} = -2.7$$

The correction is independent of dry density and adjusts the apparent moisture to true moisture regardless of dry density. This value can be used for all future tests on the same soil type.

NOTE: Each soil type having an Average Moisture Difference exceeding $\pm 1\%$ will have a moisture correction factor.

5. TEST PROCEDURE

5.1. Determine the number of soil types to be encountered on the project. If the number is substantial, then use **KT-11 MOISTURE TESTS** to determine the correct moisture content of the soil instead of calibrating the nuclear density gauge to moisture. **KT-11, Section 9. TEST PROCEDURE FOR SPEEDY METHOD** can be used if the Speedy was calibrated within the last year.

5.2. Randomly select a test site where the gauge will be at least 12 in (300 mm) away from any slight vertical projection. If the vertical projection is significant, then maintain a distance of 10 ft (3 m) including all stationary vehicles and construction equipment. Vehicles and construction equipment in motion should maintain a minimum distance of 3 to 4 ft (1 to 1.5 m) from the gauge.

5.3. Prepare the test site in the following manner:

5.3.1. Remove all loose and disturbed material, and remove additional material as necessary to expose the top of the material to be tested.

5.3.2. Prepare a horizontal area, sufficient in size to accommodate the gauge by planing a level area to a smooth condition. This will create a maximum contact surface between the nuclear gauge and material being tested.

5.3.3. The maximum void beneath the gauge shall not exceed approximately 1/8 in (3 mm). Use native soil or fine sand to fill the voids and smooth the surface with a rigid plate or other suitable tool. The depth of the filler should not exceed approximately 1/8 in (3 mm).

5.3.4. Place the nuclear gauge on the test site and trace the outline of the gauge onto the test surface. After the site selection has been made, a vertical hole is made 2 in (50 mm) deeper than the thickness of the material, with the rod and plate provided with the gauge. If the thickness of the material exceeds the depth capability of the gauge, then a hole is made 2 in (50 mm) deeper than the gauge's maximum depth.

Set the probe to the maximum depth or at a depth equal to the project specification thickness, whichever is less. Maintain alignment so the insertion of the probe will not cause the gauge to tilt from the plane of the prepared area.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

5.4. Proceed with testing in the following manner:

5.4.1. Tilt the gauge and extend the probe to the position required for the desired depth of test.

5.4.2. For uniformity, the gauge operator shall position the source rod so it is closest to the compaction equipment (point the gauge towards the roller).

5.4.3. Insert the probe in the hole.

5.4.4. Seat the gauge firmly by moving it about the probe with a back and forth motion.

5.4.5. Pull gently on the gauge in the direction that will bring the side of the probe which faces the center of the gauge into intimate contact with the side of the hole.

5.4.6. Set the time for a one-minute reading interval. Initiate the gauge to take the readings.

5.5. Take Gauge Readings.

5.5.1. Take and record 5 one-minute readings. Record the lb/ft³ (kg/m³) on Wet Density (WD) and Percent Moisture (%M) for each reading. Discard the single highest and lowest wet density values along with their accompanying percent moisture values, average the three remaining wet density values and record, and average the three remaining percent moisture values and record.

NOTE: Check tip of source rod to assure it is free of any foreign substance (i.e. grease, asphalt, concrete, etc.).

5.6. Determining Moisture Readings Using **KT-11**. Determine the moisture content of soil directly under the gauge according to **KT-11**.

5.7. If the soil fails to meet the designated compaction at a single location, rotate the gauge 180° and take new readings. If the soil compaction still fails, then the compaction is inadequate.

6. CALCULATIONS WHEN USING KT-11

6.1. Calculate the Dry Density (DD) from the Moisture Reading obtained in **Section 5.6** and the Wet Density (WD) determined by the gauge using the following equation.

$$DD = \frac{100 (WD)}{100 + \%M}$$

$$\%PR = \frac{100 (DD)}{SD}$$

Where: M = Moisture content in lb/ft³ (kg/m³)

DD = Dry Density in lb/ft³ (kg/m³)
WD = Wet Density in lb/ft³ (kg/m³)
%PR = Percent of Proctor Density (also referred to as the Percent of Standard Density)
SD = Standard Density (Proctor) lb/ft³ (kg/m³)

6.2. Dry Density may also be calculated using the equation found in **Sect. 9.5.** of **KT-41.**

7. SOIL IDENTIFICATION

7.1. Identification of the soil is required for several reasons. These include the comparison to the standards for optimum moisture content and target density which are required in order to determine compliance with the specifications, determining the proper moisture correction factors to be applied for the soil under the test, and the reporting of the moisture and density tests results.

7.2. A selection of soil type is necessary in order to set the moisture correction factor for the gauge.

7.3. Nonhomogeneous soils may be encountered in which differences between gauges and oven are not consistent between samples. In this case, the use of **KT-11, MOISTURE TESTS** is the proper method for analyzing the moisture content of the soil.

8. TESTING

8.1. Wet density and moisture are the only items the density gauge is capable of reading. All other values are calculated from wet density, moisture, and initialized information in the gauge.

9. REPORT AND RECORD

9.1. Report and record as 0.1 lb/ft³ (1 kg/m³) or 0.1% of optimum density.

Nuclear Gauge Performance Test

Applicant: _____

CIT #: _____

Employer: _____

Trials

1. Can the operator present the gauge calibration date?
2. Was the gauge “warmed up” for a minimum of 10 minutes?
3. Does the operator know how to take a standard count?
4. Did the operator put the gauge on the block correctly?
5. Was the gauge placed on 100 lb/ft³ of material for the purpose of taking standard count?

First Re-test Stopped

Pass Pass Pass
Fail Fail Fail

ASPHALT TEST KT-32

1. This section of KT-32 is necessary for what mix design? (circle one)
2. Did operator mark location with lumber crayon?
3. Was initial test taken without sand?
4. If sand was used, was excess scraped off? (Can you see the asphalt after sand is applied?)
5. Were 5 one-minute readings taken and averaged correctly?

A or B or T

First Re-test Stopped

See next page to record readings.

Reading W/O Sand

Reading W/Sand

6. _____

7. _____

8. _____

9. _____

10. _____

Avg. _____

Avg. _____

11. Is sand needed? YES or NO

Pass Pass Pass

Fail Fail Fail

Nuclear Gauge Performance Test

SOILS TEST KT-51 (4" DEPTH)

First Re-test Stopped

1. I would turn the gauge to soils mode.
2. I would make sure that site was large enough for the gauge base.
3. I would make the test hole perpendicular to the prepared surface using the guide and hole forming device.
4. I would make the test 2" deeper than the thickness of the material for direct transmission.

First Re-test Stopped

- 5. I would seat the gauge in the test location.
- 6. I would pull the gauge back to bring source rod into contact with the side of the test hole.
- 7. I would take 5 one-minute readings.
- 8. I would record wet density and percent moisture of soils.

Overall Score

Circle One

1st Test

Re-Test

Stopped

PASS

PASS

PASS

FAIL

FAIL

FAIL

Witness Examiner:

(First Try)

Signature

Date

Witness Examiner:

(Re-Test)

Signature

Date

Witness Examiner:

(Stopped)

Signature

Date