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

a. 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 5.21.02 INDEPENDENT ASSURANCE REPLICATE (ASR) CHECK FOR NUCLEAR DENSITY GAUGES.** KDOT gauges shall be calibrated at the Materials and Research Center.

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).

b. REFERENCED DOCUMENTS

b.1. KT-14; Marshall Test of Bituminous Mixes

b.2. KT-15; Bulk Specific Gravity and Unit Weight of Compacted Asphalt Mixtures

b.3. KT-39; Theoretical Maximum Specific Gravity of Asphalt Paving Mixtures

c. APPARATUS

c.1. Nuclear density gauge with supporting equipment including reference standard, survey meter and instructional material.

c.2. Core drilling equipment capable of drilling a nominal 4 in (100mm) diameter core.

c.3. Standardization.

c.3.a. 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.

c.3.b. Warm up the nuclear gauge in accordance with the manufacturer's recommendations.

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

d. TEST SITE SELECTION AND PREPARATION

d.1. Location of test site should be on a random basis as described in 5.17.06 **USING RANDOM NUMBER TABLES**. 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.

d.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.

d.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**.**

d.4. Each mix design 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:

d.4.a. Sit the gauge on a smooth level location and mark location with lumber crayon. For uniformity, position the source rod so it is closest to the laydown machine (point the gauge towards the roller).

d.4.b. Take three one-minute readings with the density gauge and record density information**.**

d.4.c. 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**.**

d.4.d. 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 density information obtained.

d.4.e. 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 one 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. It is recommended that this process be completed at three locations. An example of this calculation is as follows:

TEST SITE LOCATION	TEST SITE DENSITY[a] lb/ft^3 (kg/m^3)	TEST SITE DENSITY[a] 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)**	**+1.12 (18)**

NOTE a: Density readings in above example are the average of three one-minute readings.
The difference shows an increase in the density of more than one lb/ft^3 (16 kg/m^3) when the leveling sand is used. The use of a leveling sand is required for both the calibration process and normal testing.

e. CALIBRATION CURVE ADJUSTMENT

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 **g.**

f. CALIBRATION LOCATIONS

f.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.

f.2. For urban areas: If the bituminous mix quantities are large enough, use the rural area 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.

g. CALIBRATION PROCEDURE

g.1. Select a minimum of five locations that are typical of the bituminous mix being produced.

g.2. Take 3 one-minute readings in each location with the nuclear gauge in the backscatter or direct transmission position and mark the outline of the gauge in these locations. Determine the average for the 3 one-minute counts and record as the density for that location.

g.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.

g.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.

g.5. Obtain the core density using KT-15.

g.6. Calculations.

g.6.a. 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 percent confidence level. The following example illustrates the point:

g.6.a.1. "T" STATISTIC EXAMPLE:

CALCULATIONS FOR CALIBRATION OF NUCLEAR GAUGES ON BITUMINOUS PAVEMENT

n = Number of locations
d_i = Core Density - Nuclear Density
d_b = $\sum d_i/n$ = Correction Factor = Mean
s = Sample Standard Deviation
kg/m^3 (lb/ft^3) Nuclear = Nuclear Density, Avg. of 3 one-minute readings

kg/m^3 (lb/ft^3) Cores = Core Density, Avg. of 3 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)
1	2176	2133	43
2	2187	2160	27
3	2176	2141	35
4	2197	2168	29
5	2185	2152	33
		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 gauge readings as follows:

	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	+33	-0.4	0.16
		Total	+167		155.20

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

ENGLISH EXAMPLE:

Location	Cores (lb/ft^3)	Nuclear (lb/ft^3)	Difference(d_i)
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	2.0
		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:

	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	+2.0	-0.1	0.01
		Total	+10.7		0.63

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

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 (d_1 or d_n) and the mean (d_b). Then divide the deviation from the mean (d_b - d_1 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 percent confidence limits) for the number (n) of results considered (See Table 1) the questionable measurement may be rejected with 95 percent 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_4 because it demonstrates the largest spread from the other measurements.

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

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

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 **g.6.a.1.** using the remaining core results.

g.6.b. A minimum of four data points must pass the T-test in **g.6.a.** The standard deviation (*s*) should be less than or equal to 2.0 lb/ft^3 (32 kg/m^3). If it is larger than 2.0 lb/ft^3 (32 kg/m^3), this calibration shall be discarded.

g.6.c. The correction factor (d_b) is added to each nuclear density reading on the project to obtain a corrected nuclear density.

h. TEST PROCEDURE (HOT MIX)

h.1. Backscatter mode: Properly seat the gauge as stated in **d. TEST SITE SELECTION AND PREPARATION** and expose the source by depressing the source rod (or handle) to the first stop. Take 3 one-minute counts and average them. If any count is not within 2 lb/ft^3 (32 kg/m^3) of the average, take another count and average that value with the non-deviant values. If two are not within 2 lb/ft^3 (32 kg/m^3) of the average, discard the readings and take 3 more.

h.2. Direct transmission mode: Create a hole with the rod and hole forming device that is provided with the gauge. Lower the source into the hole to the predetermined depth.

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

i. TEST PROCEDURE (COLD RECYCLE)

i.1. Develop compaction growth curves[b] (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).

i.2. To determine in place density Use either direct transmission or backscatter as approved by the district.

NOTE b: 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.

j. CALCULATIONS

j.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.

j.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.

j.3. Density Standards.

j.3.a. 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.

j.3.b. 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.

j.4. Calculate the Wet Density (WD) value from the following:

Wet Density (WD) = indicated PCF (kg/m^3) plus the adjustment factor determined in **g. CALIBRATION PROCEDURE**.

j.5. Calculate the percent of standard from the following formula:

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

j.6. Calculate the percent voids from the following formula:

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

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

NOTE c: Density of water varies based on temperature. Determine the temperature and select the proper density for water from **TABLE 5.16.15-1.**