DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
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METHOD OF TEST FOR RELATIVE COMPACTION OF UNTREATED AND TREATED SOILS AND AGGREGATES BY THE AREA CONCEPT UTILIZING NUCLEAR GAGES

CAUTION: Prior to handling test materials, performing equipment setups, and/or conducting this method, testers are required to read "**SAFETY AND HEALTH**" in Part III of this method. It is the responsibility of whoever uses this method to consult and use departmental safety and health practices and determine the applicability of regulatory limitations before any testing is performed.

OVERVIEW

This test method provides a procedure for selecting a test area, for determining the in-place wet density and moisture of untreated and treated soils and aggregates by the use of a nuclear gage, and for determining relative compaction. Wet density measurements are made in the direct transmission position where the rod is placed into the ground.

Select a direct transmission depth as close as possible to, but not equal to or greater than, the thickness of material being tested, i.e., use a 75 mm direct transmission depth and corresponding calibration to test a layer of material 100 mm thick, and use a 125 mm direct transmission depth and corresponding calibration to a test a layer of material 150 mm thick.

The laboratory wet test maximum density shall be determined as specified in California Test 312 for Class A Cement Treated Base; and as specified in California Test 216 for untreated materials, Class B cement treated base and lime treated soils and aggregates. On the basis of specified acceptance criteria, the relative compaction values are then used to determine the compliance or noncompliance of compaction specifications within the designated area. All calculations are based on wet relationships and are made in the metric system.

NOTE: See California Test 121 of the Manual of Test, Administrative Instructions, regarding use of nuclear gages.

This test method (231) is divided into the following parts:

I. Method of field determination of in-place wet density and moisture.

II. Method of applying the area concept and determining percent relative compaction.

III. Safety and Health

PART I. METHOD OF FIELD DETERMINATION OF IN-PLACE WET DENSITY AND MOISTURE

A. APPARATUS

1. Nuclear gage and standardizing block.
2. Miscellaneous tools such as trowels, scrapers, sieve, etc. for site preparation.
3. Guide plate, approximately 300 x 460 x 6 mm.
4. Pin, approximately 20 mm diameter x 600 mm long.

B. STANDARDIZATION OF NUCLEAR GAGE FOR WET DENSITY AND MOISTURE

1. Set the standardizing block 1.5 m from any object and 8 m from any other nuclear gage. Place the gage on the standardizing block in the closed (safe) position and take four (4) 1-min density counts. Repeat the four 1-min counts for moisture in the safe position. Record on Form TL 2148 (Figure 1) and in the gage logbook. When the nuclear gage is equipped with electronic circuitry capable of automatically averaging four one-minute density and moisture standard counts simultaneously, place the gage on the standardizing block in the closed (safe) position and take the average of the four one-minute counts. Record the density and moisture standard count averages on Form TL 2148 and in the gage logbook. For additional gage operation information not covered in this paragraph, follow instructions given in the manufacturer's manual.

2. The average of the four one-minute counts determined in C.1 is to be within ±ADL (see note) of the value used to establish the calibration table.

   If it is not, contact the Radiation Safety Officer who will establish a new standard count or have the gage sent in to be checked and/or repaired. Perform the standard count *at least* once during every 8 h of operation.

   NOTE: The acceptable deviation limit (ADL) is defined in this test method as $ADL = \sqrt{n}$ where n = number of counts indicated on the gage. This relationship is valid when the number of counts is over 10,000. Table 1 shows values of ADL for various counts.

C. SITE PREPARATION

1. Remove all loose surface material and prepare a plane surface large enough to seat the gage. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 50 mm below the deepest penetration by the roller. After the surface has been prepared to a flatness and smoothness within 3 mm, use a No. 4 (4.7 mm) or smaller sieve to obtain native fines to fill minor depressions, protrusions or to correct slight lack of plane. Tamp fines and any loosened material with the guide plate.

2. Make a hole using the pin and guide plate. Extract the pin with a pin puller. A drill may be used in lieu of the pin. The depth of hole shall be 50 mm greater than the transmission depth being used. This hole must be as close as possible to 90 degrees from the plane surface. If the plate is rotated slightly around the pin and the plate does not make contact with the ground, or if it appears that the hole is crooked, make a new hole.

D. FIELD TEST FOR DENSITY DETERMINATION

1. Place the nuclear gage on the prepared surface so that the bottom of the gage is firmly seated in contact with the soil. Insert the rod into the hole to the predetermined depth. Adjust the gage so that the rod is firmly against the side of the hole that is nearest to the gage.

   Obtain a 1-min reading. Record the data as shown on Figure 1.

2. Average counts from all test sites and determine count ratio by dividing the average field count by the average standard count.

3. Find the average count ratio and corresponding direct transmission average wet density (kg/m3) on the table supplied with the gage (Example Table 2). Record the data on Figure 1.

   NOTE: No obstruction or foreign element should be within a distance of 200 mm on both sides of the *source-detector axis.* Density calibration tables for the various depths are determined in accordance with California Test 111.

E. FIELD TEST FOR MOISTURE

This test is used for cases where moistures are desired or when common composite test maximum densities are used (Part II, F).

1. Obtain a standard count for moisture as specified in Section C of this Part I.

2. For site preparation, use procedure in Section D.1 of this Part I.

3. Place the gage on the prepared surface and take a 1-min moisture count. Record the data on Figure 1.

4. Determine a count ratio by dividing the field count by the moisture standard count.

5. Find the count ratio and corresponding moisture (kg/m3) from the table supplied with the gage (Example Table 3)

   NOTE: No obstruction or foreign element should be within a distance of 250 mm *from the side of the gage.* Moisture calibration tables are determined in accordance with California Test 111.

PART II. METHOD OF APPLYING THE AREA CONCEPT AND DETERMINING PERCENT RELATIVE COMPACTION

A. SCOPE

This is a statistical procedure where a number of test measurements are taken to evaluate the state of compaction of a selected area.

B. NUMBER AND LOCATION OF NUCLEAR TESTS

1. The area concept will be used with this test. The engineer will determine from a series of density tests whether to accept or reject a designated area. The engineer shall determine the area by inspection, based on uniformity of factors affecting compaction. Insofar as possible, the area designated shall be generally homogeneous for both character of material and conditions of production and compaction. Portions of the area, which may be observed or suspected to be different from the area as a whole, will be excluded from the test. If a relative compaction test is desired for these different portions, they shall be designated as a separate test area or areas and tested separately. Do not designate test areas which include: (1) materials from separate sources, unless such materials were intermixed during placing of the compacted area; (2) materials which were placed and compacted by different types of operations or processes; or (3) material placed during different periods of production or in nonadjacent areas.

2. Select a *minimum* of 5 test sites for areas 800 m^2 or more by using a set of 10 random sample plans (Figure 3). Follow instructions given in Figure 3.

   Obtain nuclear counts at all test sites and average all counts for the area (Figure 1). If the designated test area, described in B.1, is of limited size (e.g., structure backfill, short length of shoulders, or other areas less than 800 m^2) then a *minimum* of three test sites are required.

C. DETERMINATION OF WET TEST MAXIMUM DENSITY

1. For all treated and untreated soils and aggregates, except Class A Cement Treated Bases, obtain equal representative portions of material from each nuclear test site within the area and thoroughly mix together to form a composite sample. Determine the laboratory wet test maximum density (kg/m^3) on the composite sample in accordance with California Test 216. Record the data on Form TL 2148 in the section identified as “IMPACT TEST DATA” (Figure 1). *The moisture content of the composite sample must be maintained in the same state* as *when the in-place tests were performed.* If the impact test result is to be used in a “common” composite control density, a nuclear moisture, as well as a nuclear density must be taken for each test site in an area and be averaged.

D. CORRECTION FOR OVERSIZE MATERIAL

1. A correction is applied to the composite wet test maximum density in those instances where the composite sample contains more than 10% by weight of aggregate retained on the 19 mm sieve. The data is recorded on Figure 2 in the section titled “SAMPLE FOR ROCK CORRECTION”. California Test 216 shows details for handling rock corrections.

E. PERCENT RELATIVE COMPACTION

1. Calculate percent relative compaction as follows:

   Percent relative compaction = [(Average In-Place Wet Density)/(Composite Wet Test Maximum Density)] x 100

2. The calculations for cases where there is 10% or less of +19 mm aggregate is shown on

Figure 1. Note that gage readings for the individual sites are averaged and a mean percent relative compaction calculated for the area.

3. The calculations for cases where there is more than 10% of + 19 mm aggregate is shown in Figure 1.

4. The average relative compaction of the test sites in an area must be at or above the specified minimum compaction density for acceptance of the compaction in the area. The percent relative compaction value is calculated to the nearest 0.1% and then reported as a whole number. For rounding the average percent relative compaction value (Test Result), if the computed value ends in a number with a fractional portion 0.5 or greater, report as the next higher whole number. If the computed value ends in a number with fractional portion less than 0.5, report without changing the whole number.

   Example:

Computed Value	Reporting Value
94.5 to 95.0%	95%
95.0 to 95.4%	

F. WET COMMON-COMPOSITE TEST MAXIMUM VALUE

1. In many cases where the material is the "same", it is permissible to use a *"common"* wet composite test maximum density for use in different areas in lieu of that specified in Section C.1 of this Part II. For a material to be the same, it must comply with the following general criteria:

   a. It must be from the same general source (excavation area, balance point, plant, etc.).

   b. It must generally have the same visual characteristics of color, gradation, and type of soil.

   c. The average in-place moistures must be the "same". Adjustments in moisture are to be made to meet this criteria when *"common"* wet composite test maximum values are used.

2. A *"common"* wet composite test maximum density is initially established by averaging two consecutive wet composite test maximum densities which are within 50 kg/m^3 density and performed within three days. The average moistures between the areas represented by the two consecutive wet composite test maximum values must also be within 50 kg/m^3.

3. Anytime that a wet composite test maximum density is determined for an area, it shall be used to calculate the percent relative compaction for that area.

4. A *"check"* wet composite test maximum must be performed at *least* every 7th calendar day or after the *"common"* wet composite test maximum density has been used for 14 areas, whichever comes first.

   a. If the *"check"* test is within 50 kg/m^3 moisture and density of the *"common"* density, the two values are averaged to establish a new *"common"* density and average moisture. If it is not, wet composite test maximum densities must be performed for each compaction test area until the criteria for F-2 of this PART II are met.

5. If average relative moistures between areas differ and a common composite test maximum is to be established, a correction is applied. The following example illustrates use of a common composite test maximum with moisture corrections. Anytime the engineer judges conditions have changed, a new common composite test maximum should be established. An example where a common composite test maximum is used is shown in Figure 2.

PART III. SAFETY AND HEALTH

Personnel are required to be trained by a qualified instructor approved by the California Department of Health and the Divisions of Industrial Safety.

Caltrans personnel are required to read and be familiar with California Test 121, Administrative Instructions for Use of Nuclear Gages. Caltrans personnel are required to wear a film badge.

This method does not purport to address all the safety problems associated with its use.

REFERENCES:

California Tests 121, 216, 312, and 911

End of Text (14 Pages) on California Test 231

Example:

	Area I	Area II	Area III	Area IV	Area V	Area VI
Date..	4-18-96	4-19-96	4-20-96	4-21-96	4-25-96	4-26-96
Average In-Place Wet Density, kg/m^3....	2040	2150	2060	2080	2120	2110
Average In-Place Moisture, kg/m^3..........	90	110	140	80	130	100
Wet Composite Test Maximum Density, kg/m^3..............................	2150	2200	-	-	2160	-
Common Composite Wet Test Maximum Density, kg/m^3................................	-	-	2175	2175	-	2168
(Average Moisture, kg/m^3)	-	-	(100)	(100)	-	(115)
Moisture Correction, kg/m^3.....................	-	-	-40	+20	-	+15

a. Area I

$$\text{\% Relative Compaction} = \frac{2040}{2150} \times 100 = 95\%$$

b. Area II

$$\text{\% Relative Compaction} = \frac{2150}{2200} \times 100 = 98\%$$

c. Area III

$$\text{Moisture Correction} = \left(\frac{90 + 110}{2}\right) - 140 = -40$$

$$\text{Common Composite Test Max} = \frac{2150 + 2200}{2} = 2175$$

$$\text{\% Relative Compaction} = \frac{2060 - 40}{2175} \times 100 = 93\%$$

See sample forms figures1 and 2.

State of California — ## Relative Compaction Test-Nuclear — **Dept of Transportation**

Job Stamp	Contract	Test No.
	Type of Material	
	Material From	
	Impact By	Nuclear By
	Date	Date
Show Test Location and Area Limits	Nonbiased Plan No.	Gage No.

In-Place Test by Nuclear

	Site	Den. Ct.___mm	Std. Ct. Density
A	1		
	2		
	3		Σ
	4		F $\bar{X}$
			Moist Count
	5		1
			2
	6		3
			4
	7		5
			6
	8		7
			8
B	Σ		Σ
C	$\bar{X}$		G $\bar{X}$
CR(C/F)			CR(G/I
D	$\bar{X}$ Den. g/ml		H $\bar{X}$ H2O g/ml
E	$\bar{X}$ Den. Corr. For Moist.**±		

Std. Count Moist: Σ; I $\bar{X}$

**E = D ± Diff. Bet. $\bar{X}$ Moist.Fr. Common TM & H

Percent Relative Compaction		Spec.	Individual	
			Moving Ave.	

*E/K for10% ≤ + 19mm E/W for > 10% + 19mm

If Common Test Maximum is used ($\bar{X}$) K or W = $\bar{X}$ H2O=

From Tests: Dated:

Remarks:

Impact Test Data

J	Initial Wet Weight of Test Specimen (g)				
	Specimen	1	2	3	4
	Water Adjustment				
	Tamper Reading				
K	Wet Density				

K From Table 1Test Method 216. Highest Density is Test Max.

L (+) 19mm Agg. Adj.

% + 19mm (Q) Adj.	
20 or less	1.00
21-25	0.99
26-30	0.98
31-35	0.97
36-40	0.96
41-45	0.95
46-50	0.94

Sample for Rock Correction

M	Total Sample Wt.	(g)	
N	+ 19mm Wt.in Air	(g)	
O	+ 19mm Wt. In Water	(g)	
P	+ 19mm Vol	(N-O)	
Q	% + 19mm	100(N/M)	
R	% - 19mm	(100-Q)	
S	Density of + 19mm	(N/P)	
T	% + 19mm /Den. Of + 19mm	(Q/SL)	
U	% -19mm /Den. Of - 19mı	(R/K)	
V	Sum of T and U	(T+U)	
W	Adjusted Density	(100/V)	

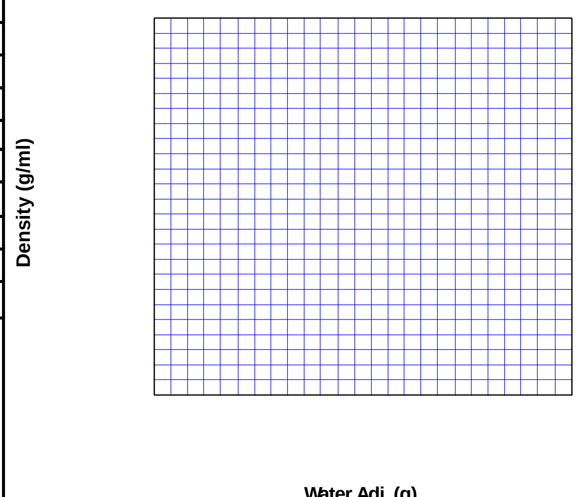
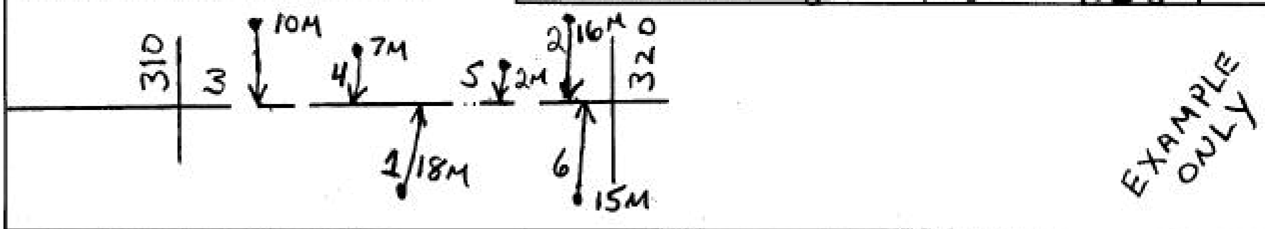


Figure 1

State of California	**Relative Compaction Test-Nuclear**	Dept of Transportation
Job Stamp	Contract	Test No. 25
	Type of Material EMB	
	Material From	
	Impact By FC	Nuclear By BL
	Date 03/30/00	Date 03/30/00
Show Test Location and Area Limits	Nonbiased Plan No. 8	Gage No. NE 59



In-Place Test by Nuclear

	Site	Den. Ct. 200mm		Std. Ct. Density	J
A	1	46658		51547	
				51522	
	2	44598		51904	
				51267	K
	3	49747			
			Σ	206240	L
	4	46453	F	x̄ 51560	
			Moist Count		
	5	47741	1		
			2		
	6	46380	3		
			4		
	7		5		
			6		
	8		7		
			8		
B	Σ	281577	Σ		
C	x̄	46930	G	x̄	
CR(C/F)		.910	CR(G/I		
D	x̄ Den. g/ml	2.23	H	x̄ H2O g/ml	Σ
E	x̄ Den. Corr. For Moist.**±				I x̄

**E = D ± Diff. Bet. x̄ Moist.Fr. Common TM & H

Percent Relative Compaction	89	Spec.	Individual	90
			Moving Ave.	

*E/K for10% ≤ + 19mm E/W for > 10% + 19mm

If Common Test Maximum is used (x̄) K or W = x̄ H2O=

From Tests: Dated:

Remarks:

K From Table 1Test Method 216. Highest Density is Test Max.

L (+) 19mm Agg. Adj.
% + 19mm (Q) Adj.
20 or less 1.00
21-25 0.99
26-30 0.98
31-35 0.97
36-40 0.96
41-45 0.95
46-50 0.94
Std. Count Moist

Impact Test Data

Initial Wet Weight of Test Specimen			(g)	2700
Specimen	1	2	3	4
Water Adjustment	0	+50	+100	
Tamper Reading	10.5	10.3	10.4	
Wet Density	2.44	2.48	2.46	

Sample for Rock Correction

M	Total Sample Wt.	(g)	14000
N	+ 19mm Wt.in Air	(g)	2380
O	+ 19mm Wt. In Water	(g)	1465
P	+ 19mm Vol	(N-O)	915
Q	% + 19mm	100(N/M)	17.0
R	% - 19mm	(100-Q)	83.0
S	Density of + 19mm	(N/P)	2.60
T	% + 19mm /Den. Of + 19mm	(Q/SL)	6.5
U	% -19mm /Den. Of - 19mm	(R/K)	33.5
V	Sum of T and U	(T+U)	40.0
W	Adjusted Density	(100/V)	2.50

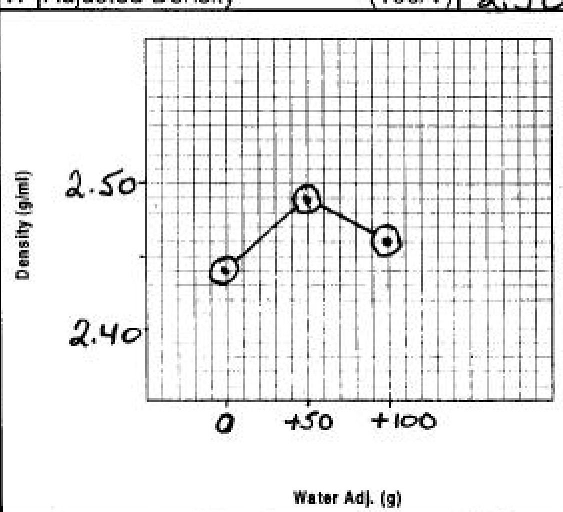


Figure 2

NONBIASED SAMPLE PLANS

Once an area is selected on the basis of uniformity of factors, nonbiased location of measurement sites is required for applying statistical control procedures. The nonbiased sample location plans will randomly locate the approximate measurement sites.

NOTE: The number of measurement sites must be determined after the area has been determined and *before* any tests performed.

PROCEDURE FOR USE OF NONBIASED SAMPLE PLANS

1 a. Use the last digit from the first reading taken for the daily standard count to select the plan for the first area. For subsequent areas, use the last digit from the second, third, and fourth readings. If five through nine areas are tested, use the second to the last digit from the first through the fourth readings taken for the daily standard count.

b. For nuclear gages that electronically average the standard counts — Take a $^{1}/_{4}$ minute count in the safe position at any convenient location, i.e., ground, truck bed, carry case, etc., prior to selecting the plan for an area. Use the last digit of the density reading for selecting the plan. A new count should be taken for each area.

2. Visualize the plan as a map of the area to be sampled.

3. Each dot represents a measurement site. There are ten dots numbered from one (1) through ten (10). If you are to take a five- (5) site test, then use the dots numbered from one (1) through five (5). If a three-site test is going to be used, then use the locations of the first three dots. This procedure will be used for all tests, with Number 1 dot the first site, Number 2 dot the second site and so on until the desired number of sites have been used.

4. Test at the approximate locations on the grade represented by the dots on the plan. Some adjustments are necessary for irregular areas. (See Figure 3)

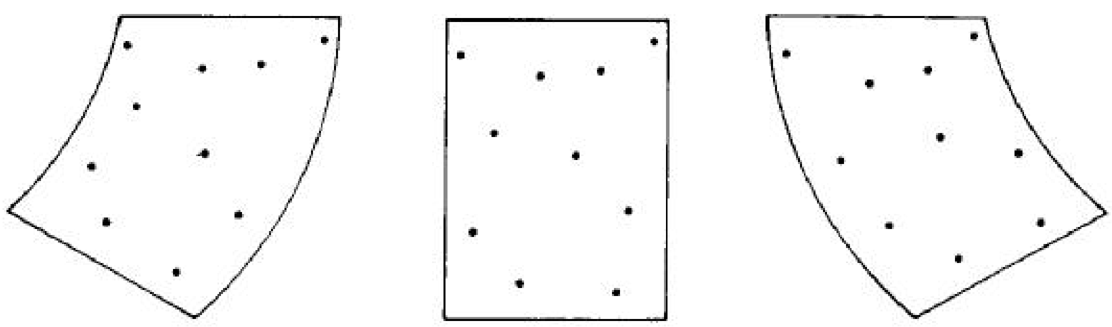
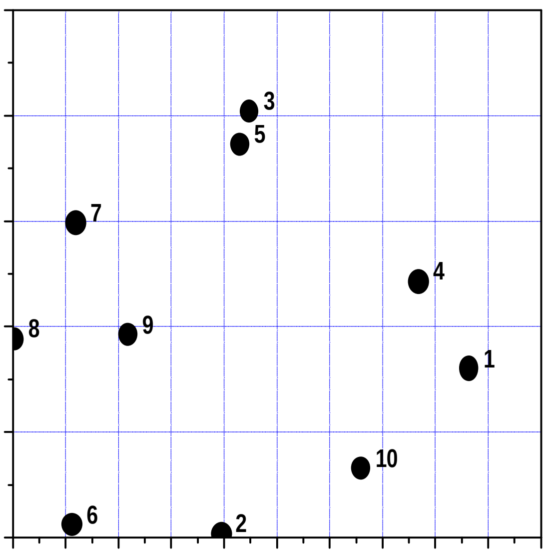


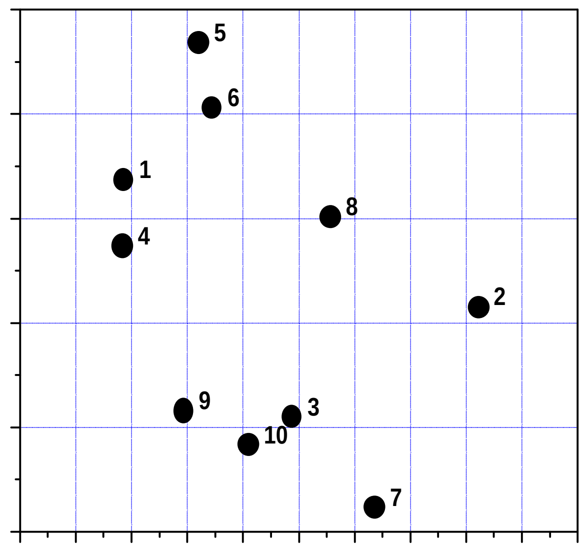
Figure 3

Figure 3 Cont.

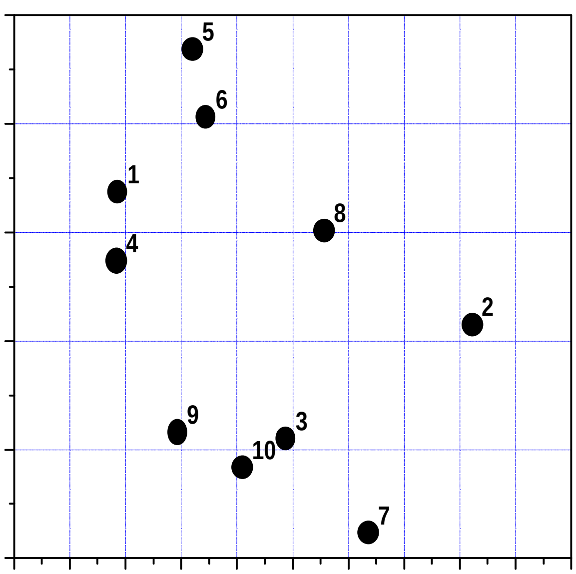
NONBIASED PLAN 1



NONBIASED PLAN 2



NONBIASED PLAN #3



NONBIASED PLAN #4

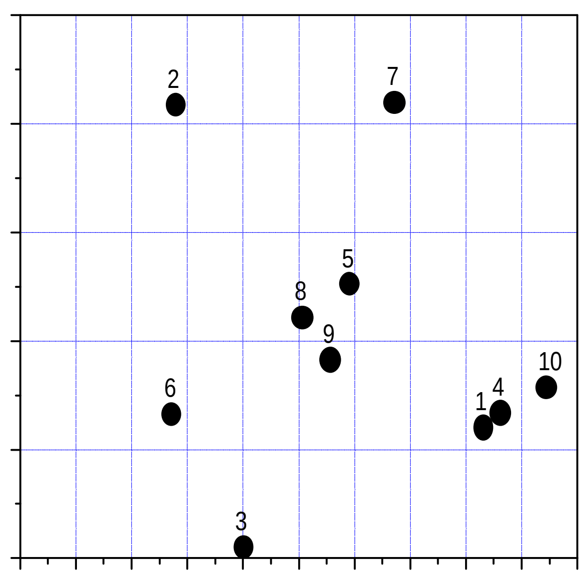
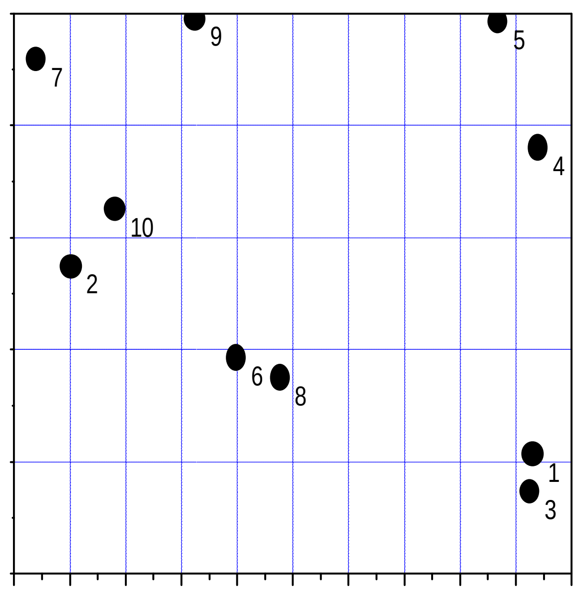
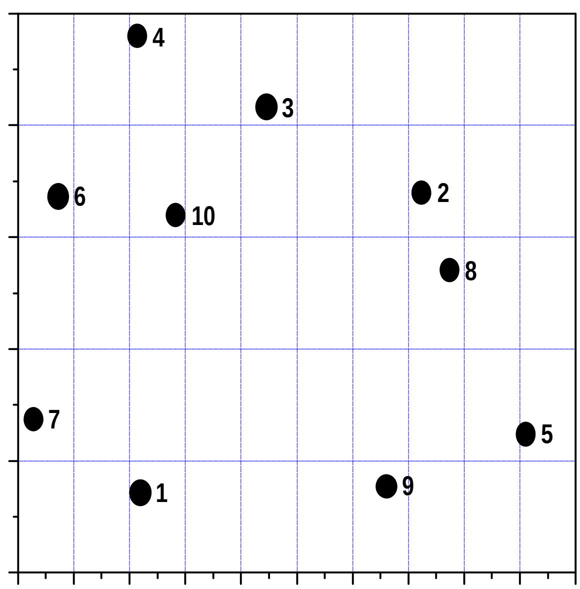


Figure 3 Cont.

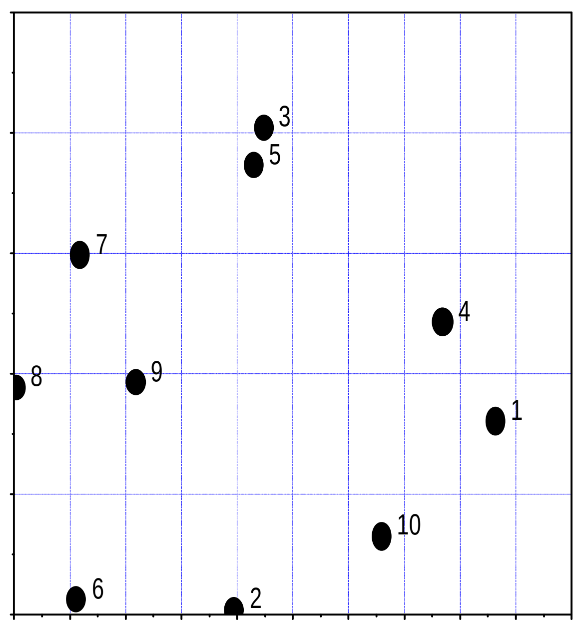
NONBIASED PLAN 5



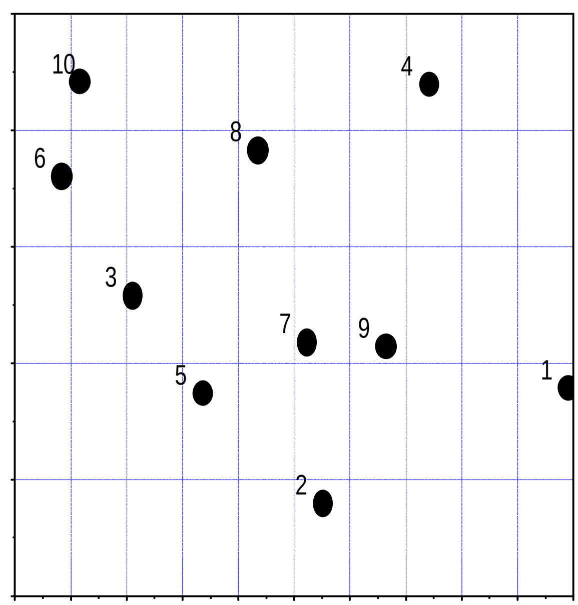
NONBIASED PLAN 6



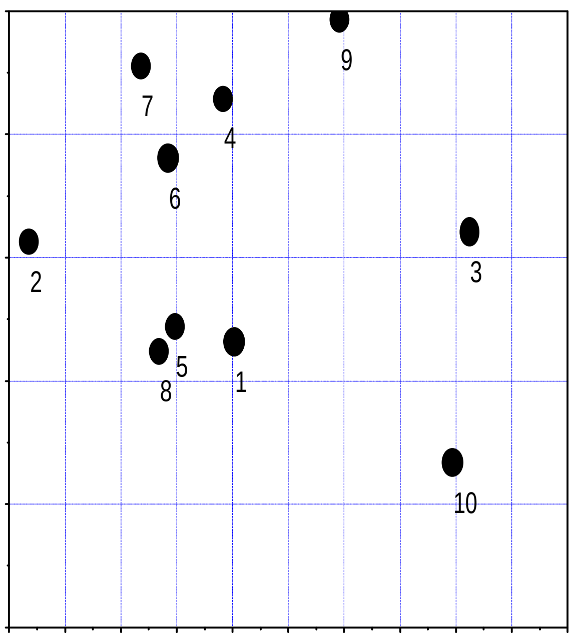
NONBIASED PLAN #7



NONBIASED PLAN #8



NONBIASED PLAN 9



NONBIASED PLAN 10

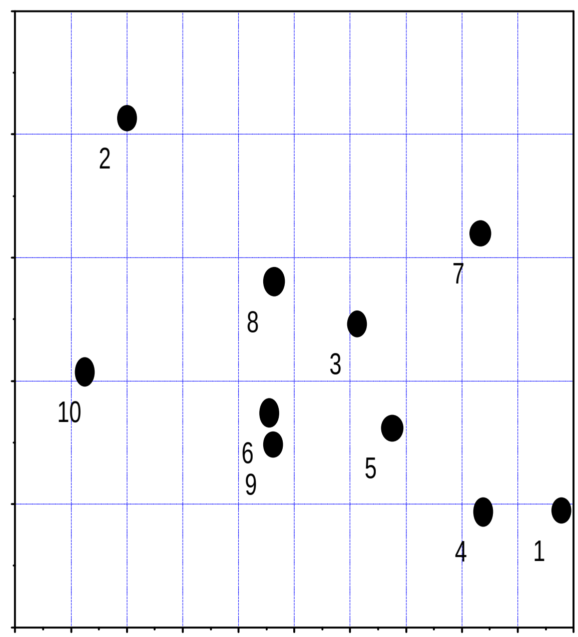


Figure 3 Cont.

TABLE 2
COUNT RATIO VS. DENSITY FOR NUCLEAR GAGE NO. NE 59

District 19 January 3, 1978 Std. Ct 51500 200 mm D/T By B. Lister

BASED ON:							
	DENSITY (kg/m3)	1532	1636	2018	2153	2680	2771
	COUNT RATIO	1.791	1.553	1.192	.933	.597	.542

CR TO CR	kg/m3	CR TO CR	kg/m3	CR TO CR	kg/m3
2.000-2.018	1400	1.364-1.376	1800	.931- .939	2200
1.981-1.999	1410	1.351-1.363	1810	.922- .930	2210
1.962-1.980	1420	1.338-1.350	1820	.913- .921	2220
1.943-1.961	1430	1.326-1.337	1830	.905- .912	2230
1.925-1.942	1440	1.313-1.325	1840	.896- .904	2240
1.907-1.924	1450	1.300-1.312	1850	.887- .895	2250
1.888-1.906	1460	1.288-1.299	1860	.879- .886	2260
1.870-1.887	1470	1.276-1.287	1870	.874- .878	2270
1.853-1.869	1480	1.264-1.275	1880	.862- .870	2280
1.835-1.852	1490	1.252-1.263	1890	.854- .861	2290
1.817-1.834	1500	1.240-1.251	1900	.846- .853	2300
1.800-1.816	1510	1.228-1.239	1910	.838- .845	2310
1.783-1.799	1520	1.216-1.227	1920	.830- .837	2320
1.766-1.782	1530	1.205-1.215	1930	.822- .829	2330
1.749-1.765	1540	1.193-1.204	1940	.814- .821	2340
1.733-1.748	1550	1.182-1.192	1950	.807- .813	2350
1.716-1.732	1560	1.171-1.181	1960	.799- .806	2360
1.700-1.715	1570	1.160-1.170	1970	.791- .798	2370
1.684-1.699	1580	1.148-1.159	1980	.784- .790	2380
1.667-1.683	1590	1.138-1.147	1990	.776- .783	2390
1.652-1.666	1600	1.127-1.137	2000	.769- .775	2400
1.636-1.651	1610	1.116-1.126	2010	.762- .768	2410
1.620-1.635	1620	1.105-1.115	2020	.755- .761	2420
1.605-1.619	1630	1.095-1.104	2030	.747- .754	2430
1.590-1.604	1640	1.085-1.094	2040	.740- .746	2440
1.574-1.589	1650	1.074-1.084	2050	.733- .739	2450
1.560-1.573	1660	1.064-1.073	2060	.726- .732	2460
1.545-1.559	1670	1.054-1.063	2070	.719- .725	2470
1.530-1.544	1680	1.044-1.053	2080	.713- .718	2480
1.515-1.529	1690	1.034-1.043	2090	.706- .712	2490
1.501-1.514	1700	1.024-1.033	2100	.699- .705	2500
1.487-1.500	1710	1.014-1.023	2110	.692- .698	2510
1.473-1.486	1720	1.005-1.013	2120	.686- .691	2520
1.458-1.472	1730	.995-1.004	2130	.679- .685	2530
1.445-1.457	1740	.986- .994	2140	.673- .678	2540
1.431-1.444	1750	.976- .985	2150	.667- .672	2550
1.417-1.430	1760	.967- .975	2160	.660- .666	2560
1.404-1.416	1770	.958- .966	2170	.654- .659	2570
1.390-1.403	1780	.949- .957	2180	.648- .653	2580
1.377-1.389	1790	.940- .948	2190	.642- .647	2590

TABLE 3

COUNT RATIO VS DENSITY FOR NUCLEAR GAUGE NO. NE 59

District 19, January 3, 1978, Std. Ct 11400 By B. Lister

BASED ON kg/m3	0	303
COUNT RATIO	.168	.686

CR TO CR	kg/m3	CR TO CR	kg/m3	CR TO CR	kg/m3
.155- . 171	00	.501- . 517	200	.847- .863	400
.172- . 188	10	.518- . 534	210	.864- .880	410
.189- .206	20	.535- . 552	220	.881- .897	420
.207- .223	30	.553- .569	230	.898- . 915	430
.224- . 240	40	.570- .586	240	.916- .932	440
.241- .258	50	.587- . 603	250	.933- . 949	450
.259- . 275	60	.604- .621	260	.950- .967	460
.276- .292	70	.622- . 638	270	.968- .984	470
.293- . 309	80	.639- .655	280	.985-1.001	480
.310- .327	90	.656- .673	290	1.002-1.018	490
.328- .344	100	.674- .690	300	1.019-1.036	500
.345- .361	110	.691- .707	310	1.037-1.053	510
.362- . 379	120	.708- .724	320	1.054-1.070	520
.380- .396	130	.725- . 742	330	1.071-1.088	530
.397- .413	140	.743- .759	340	1.089-1.105	540
.414- . 431	150	.760- .776	350	1.106-1.122	550
.432- .448	160	.777- .794	360	1.123-1.140	560
.449- .465	170	.795- . 811	370	1.141-1.157	570
.466- .482	180	.812- . 828	380	1.158-1.174	580
.483- . 500	190	.829- .846	390	1.175-1.191	590