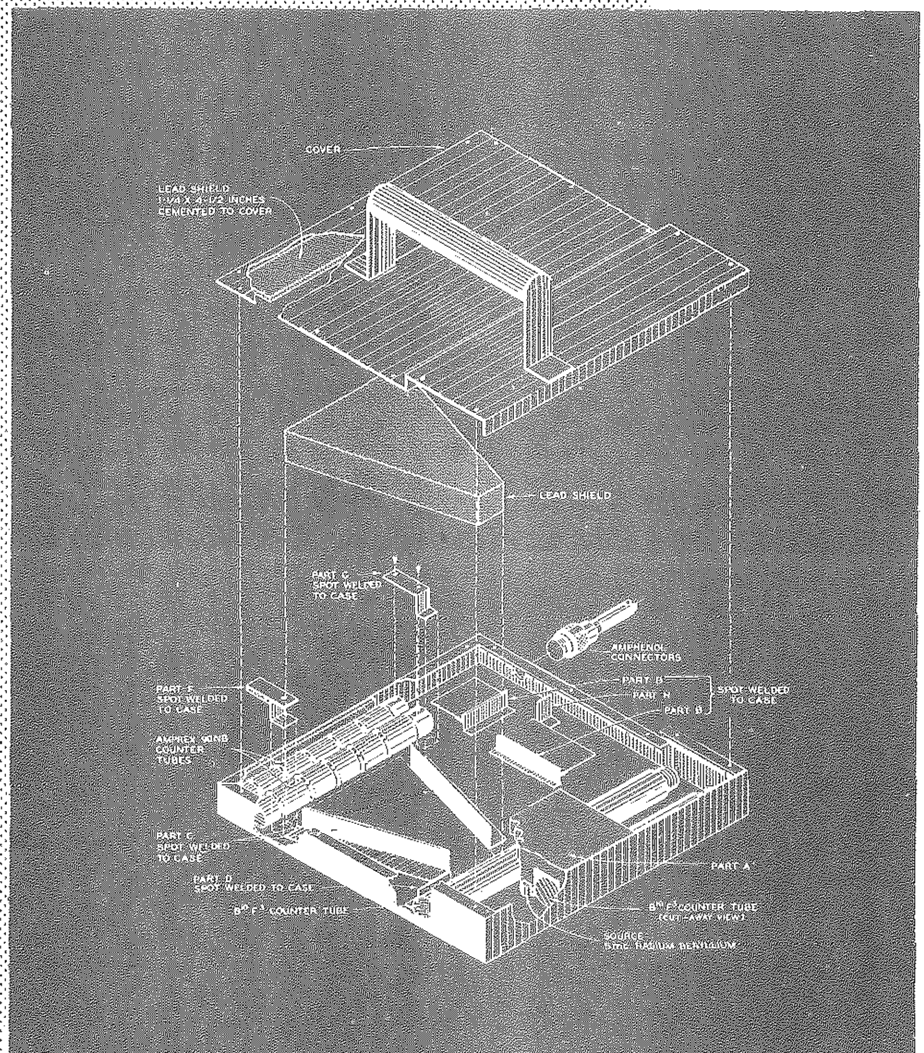
R-316

The MICHIGAN NUCLEAR COMBINATION DENSITY-MOISTURE SURFACE GAGE



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MICHIGAN
STATE HIGHWAY DEPARTMENT

JOHN C. MACKIE
COMMISSIONER

THE MICHIGAN NUCLEAR COMBINATION DENSITY-MOISTURE SURFACE GAGE

Bryant W. Pocock
Lee W. Smith
William H. Schwartje
Richard E. Hanna

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As early as 1952, the Michigan State Highway Department recognized the potential implications which the rapidly expanding field of atomic energy and radioactivity might have in the transportation engineering profession. An Isotopes Section was created during the year within the Research Laboratory Division, Office of Testing and Research, for the purpose of investigating possible applications of radioactive materials in testing procedures, and of developing nuclear tests where feasible.

It became almost immediately apparent that nuclear techniques possessed considerable promise in the measurement of densities and moisture contents of soils. Research reported simultaneously by two independent groups, Belcher, Herner, Cuykendall, and Sack (1), and Lane, Torchinsky, and Spinks (2), showed that nondestructive determinations of soil density and moisture content could be made by using gamma rays and fast neutrons respectively. These reports and several others which have appeared up to the present time (3-18) suggested that the development of a satisfactory nuclear gage is fundamentally a matter of proper design.

It is the purpose of this paper to report some of the experiences of the Michigan State Highway Department with a nuclear combination density-moisture surface gage of its own design, and to discuss certain results obtained by field density crews using duplicates of this gage for compaction control during normal highway construction.

General Description of the Gage

The Michigan nuclear combination density-moisture surface gage is a nondestructive device which depends for its operation on the interaction between nuclear radiation and matter. Instrumentation consists of two major components: the gage and a portable scaler (electronic counter).

The gage is a stainless steel box about ten inches square, an inch and a half in height, with a handle across the top. Total weight is about 18 lb. A sealed metal capsule about the size of a lead pencil eraser is

Figure 1. The Michigan nuclear combination density-moisture surface gage connected to portable scaler.

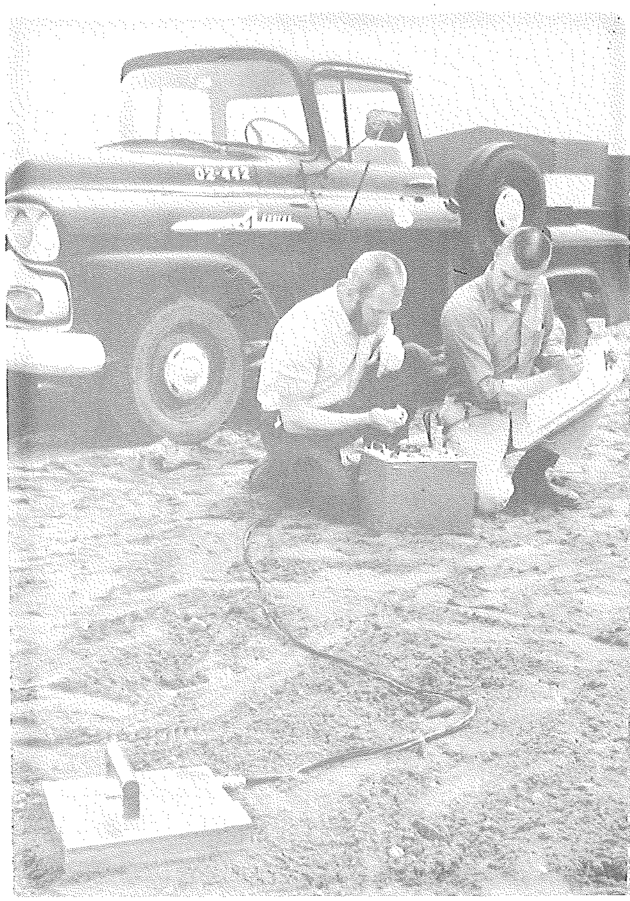
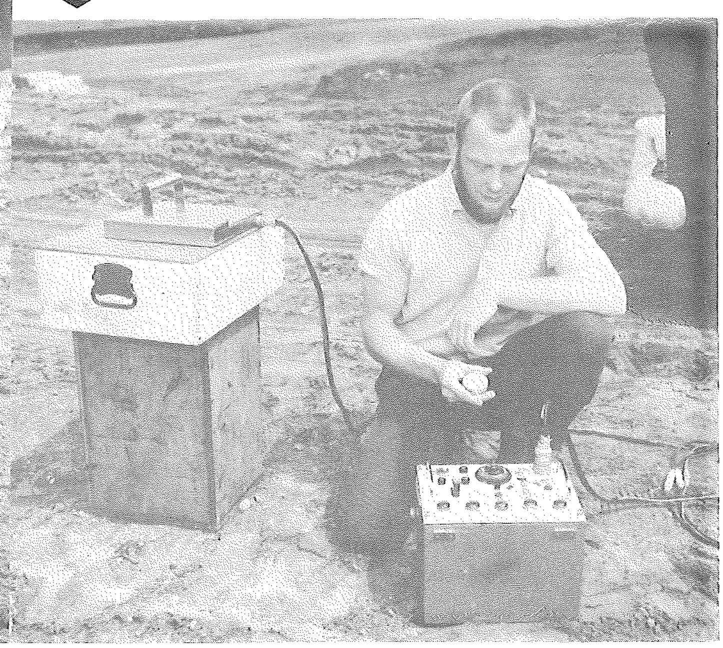


Figure 2. The Michigan gage being operated by a density control crew.

Figure 3. Density and moisture count rates being determined on the reference standard with the Michigan gage.



embedded in a lead block inside the gage. This capsule contains a tiny amount (about five millicuries) of radium 226-beryllium, which furnishes the radiation for the interactions with the soil. The radiation is of two kinds, gamma rays and fast neutrons. The gamma rays are used to measure density, and the neutrons to measure moisture. Since radium has a half-life of 1620 years, the radiation is relatively constant.

The gage is connected through a cable to a portable scaler equipped with a switch which enables the operator to record either the density or the moisture content of the soil. Figures 1 through 4 show the general appearance of the gage and most of its design features. A schematic diagram is given in Figure 13 of the Appendix.

A unique feature of the Michigan gage is its use with a single reference standard employed for both density and moisture in eliminating the effects of changes in background radiation. This standard is a wooden box completely filled with plywood sheets treated with a commercial water repellent and capped with quarter-inch Masonite for durability. Dimensions are 7 in. high, 15 in. wide, and 20 in. long. Weight is about 50 lb. In use it is placed on an empty wood box with the Masonite uppermost in order to maintain a constant elevation above ground. The gage is positioned within the outline scribed on the Masonite and count rates are determined for both density and moisture. These rates are referred

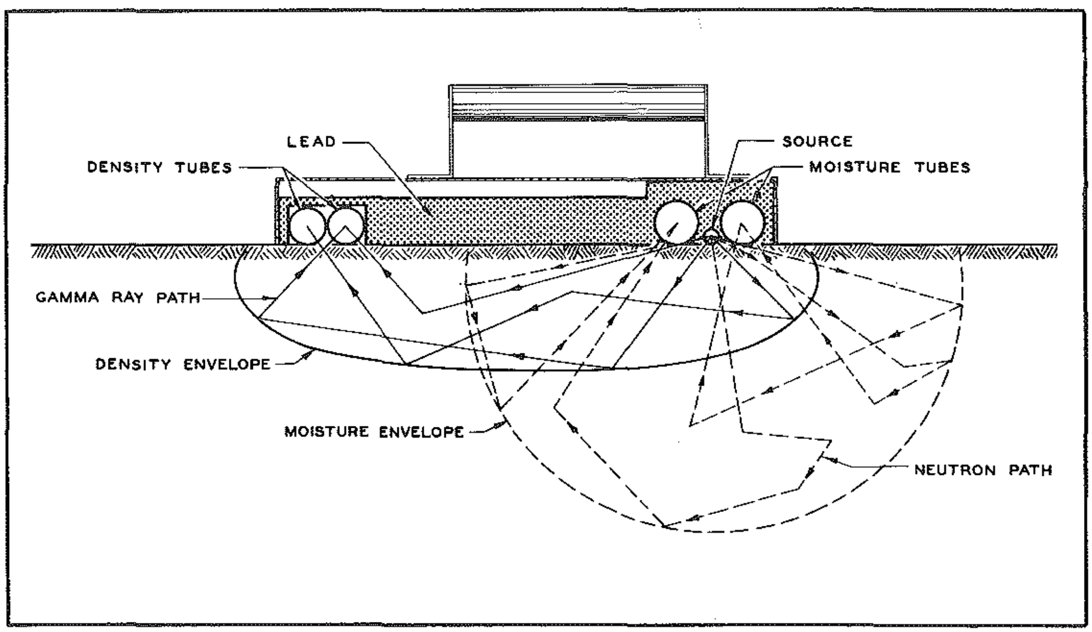


Figure 4. Schematic representation of paths of gamma rays and neutrons through the soil under the gage.

to previously selected standard rates and all field count rates are adjusted by the difference for the next four hours in practice. Wood is used as a moisture as well as a density standard because it contains an abundant supply of hydrogen atoms.

Theory of the Gage

When gamma rays come into contact with matter of any kind, they are either scattered or absorbed or both. Other phenomena may also occur, depending upon the energy of the gamma rays and the properties of the target material; but the density portion of the Michigan gage is based almost exclusively on the scattering and absorption of gamma radiation.

The gage is so designed that practically all gamma rays reaching the sensing elements (gamma ray detecting tubes) first must pass through a layer of whatever material the gage is placed upon. If there were nothing under the gage, very few gamma rays would reach the tubes, since these are shielded from the source by a lead absorber. As the material under the gage becomes denser, more gamma rays are scattered in all directions, and more are able to reach the tubes and be counted.

As the density continues to increase, however, so does the absorption within the material, and a point is reached at which absorption increases more rapidly than scattering. This point occurs just below the density of water and explains why the density calibration curve rises to a peak, then falls off sharply, as shown in Figure 5. Soils being of greater density than water, these are found on the descending portion of the curve. This means that the greater the density, the lower is the count rate reported by the gage (Figure 6).

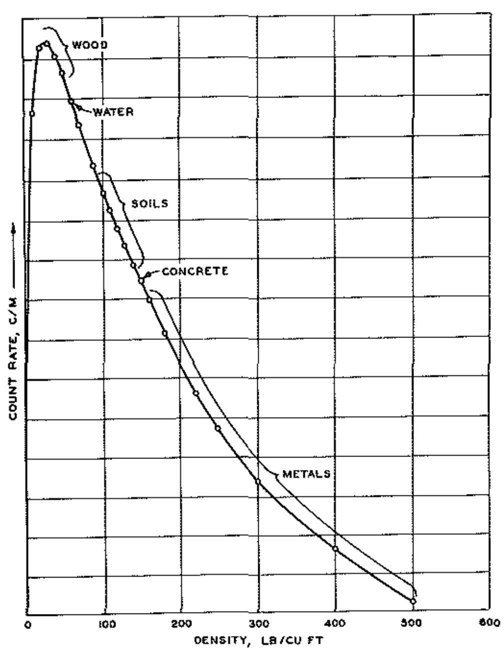


Figure 5. Density Curve

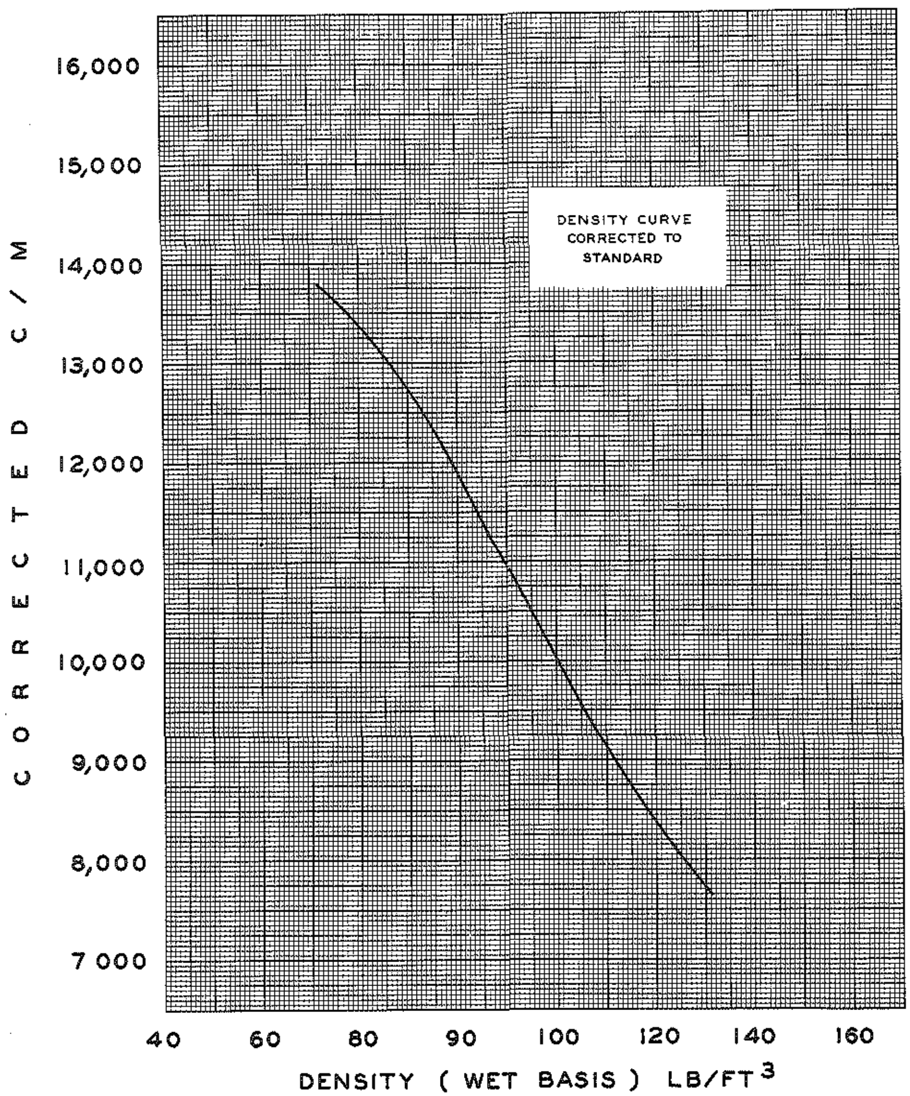


Figure 6. Calibration Curve for Density
MSHD Combination Nuclear Density-Moisture Gage.

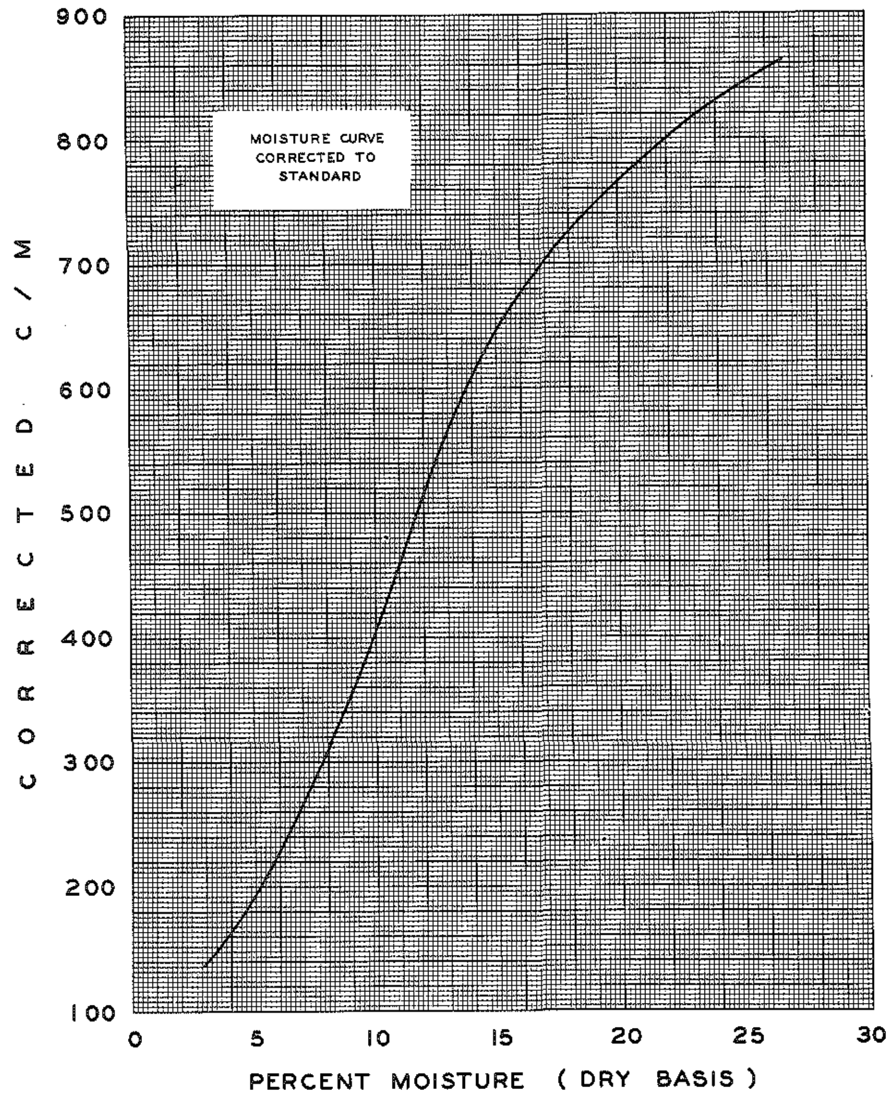


Figure 7. Calibration Curve for Moisture
MSHD Combination Nuclear Density-Moisture Gage.

When fast neutrons (about 10^6 electron volts) come into contact with matter, they are most effectively slowed to thermal velocities (about 0.035 electron volts) by elastic collisions with the nuclei of hydrogen atoms. Hydrogen-bearing materials, therefore, will slow down fast neutrons much more rapidly than will materials containing no hydrogen. Since the detector tubes in the moisture portion of the gage are sensitive only to slow neutrons, their count rate is directly proportional to the moisture content of the material under the gage (Figure 7).

Van Bavel, Underwood, and Ragar (19) have challenged the validity of surface gages of this type on the ground that they are wholly dependent on Compton scattering, and that Compton scattering is a function of the atomic numbers of the soil particles. These authors maintain that nuclear gages utilizing scattered gamma radiation will be highly susceptible to soil type and therefore will never be satisfactory in practice. Validity, they claim, can be achieved only with gages which are independent of Compton scattering and which operate solely by absorption.

Pocock (20) has alluded to the close correlation which exists between the densities of materials and their atomic numbers. Within the ranges of densities and soil types normally experienced, it is to be expected that density will largely reflect the effective average atomic number of the material (the so-called "Z effect"). Furthermore, as pointed out above, the absorption of gamma rays greatly outweighs their scattering with materials denser than water, as shown by the density calibration curve of the Michigan gage. In practice, soil type has had no demonstrable influence on the operation of the gage up to this writing.

Similarly, the absorption of neutrons is a complex function of the density, atomic number, and cross section (target value) of the absorbing material, as well as of the energy of the neutrons. Within the range of interest (soils), the effect of compaction upon the volume of the sphere of influence of the moisture portion of the gage can be predicted on these theoretical grounds to be an inverse function. In other words, the greater the compaction, the smaller is the volume which the gage "sees." The fact that it has been possible to calibrate the moisture portion of the gage directly in units of percent by weight, irrespective of density, indicates that this relation is close to linear.

Calibration and Field Use

The first Michigan combination gage was calibrated using laboratory volume-weight data covering a wide range of materials and moisture contents. The calibration curves were then checked in the field against results obtained by conventional balloon density tests and moisture determinations made at the site with portable hot plates and balances.

It was found that results from conventional tests taken at various experimental sites were scattered about equally on both sides of the calibration curves, with the mean deviation of 70 nuclear density determinations being 0.014 lb per cu ft less than the corresponding conventional determinations, and that of 70 nuclear moisture measurements being 0.211 percent moisture by weight less than the corresponding conventional measurements. Soils included in the comparison tests were clay, sand, crushed stone, foundry sand, 23-A, 22-A, base course, selected subbase, and mixtures of sand and selected subbase materials.

Figures 8 and 9 show nuclear density and moisture results plotted against corresponding conventional results for these determinations. The correlation coefficients are 0.941 and 0.979 respectively. Original data used in this analysis are given in Table 1 in the Appendix.

It was largely as a result of these comparison tests that the decision was made to put the gage into use on a regular construction project and have it operated by an ordinary density control crew of two men. Accordingly, on March 18, 1959, it was placed in operation on the US 12 Relocation near Marshall, in Projects BI 13082, C1RN, and BI 13083, C1RN, C2RN, C3RN, and C4RN, under the control of the regular density crew, who were brought into the laboratory and briefed on its operation.

On the basis of results obtained with the prototype gage, in the above construction project, the Administration authorized construction of five additional gages for field use. As these gages were completed, they were put into use by density control personnel trained by the Isotopes Section and operating on various construction projects in Michigan's Lower Peninsula. Comparisons between nuclear and conventional results are shown in Figures 8 through 11, and in Tables 1 and 2 in the Appendix.

Accuracy of the Gage

Figures 10 and 11 show results of 159 nuclear density and 172 nuclear moisture determinations on the US 12 Relocation, plotted against corresponding conventional results. Soils involved in the study included sand; clay; sand and clay; sand and gravel; sand-gravel-clay mixtures; stony sand and clay; very stony material; sand, clay, and stone; and sand, gravel, and silt.

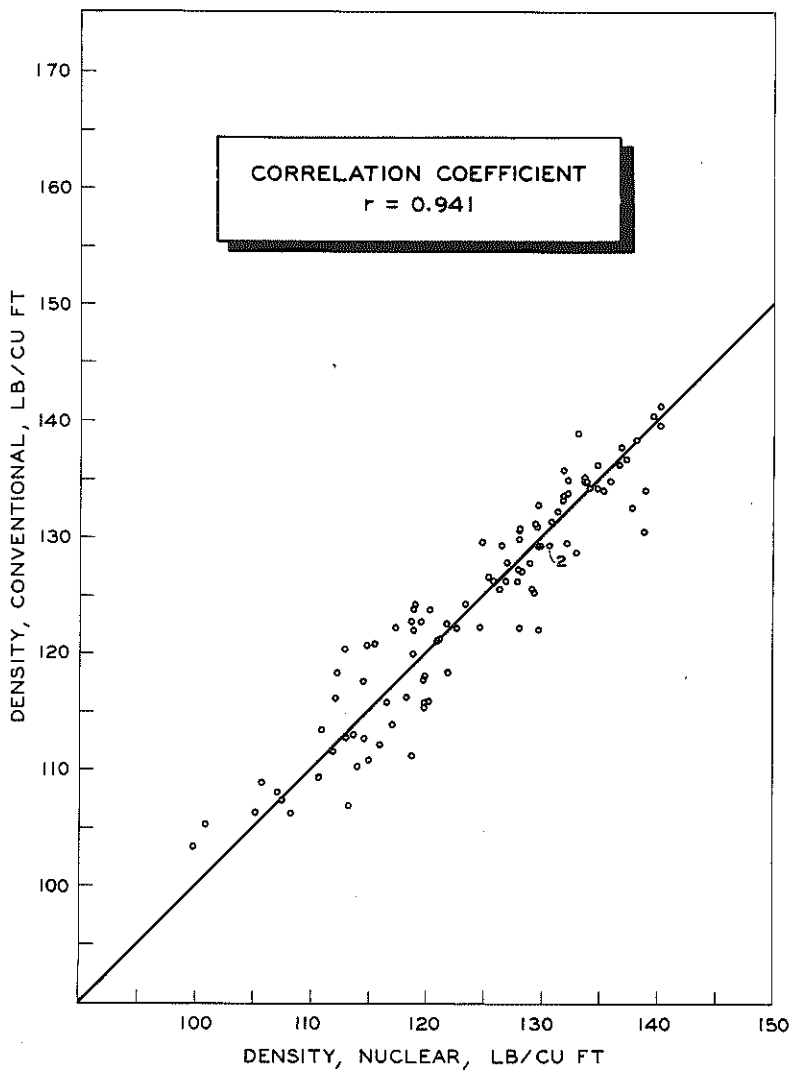


Figure 8. Conventional vs Nuclear Density.

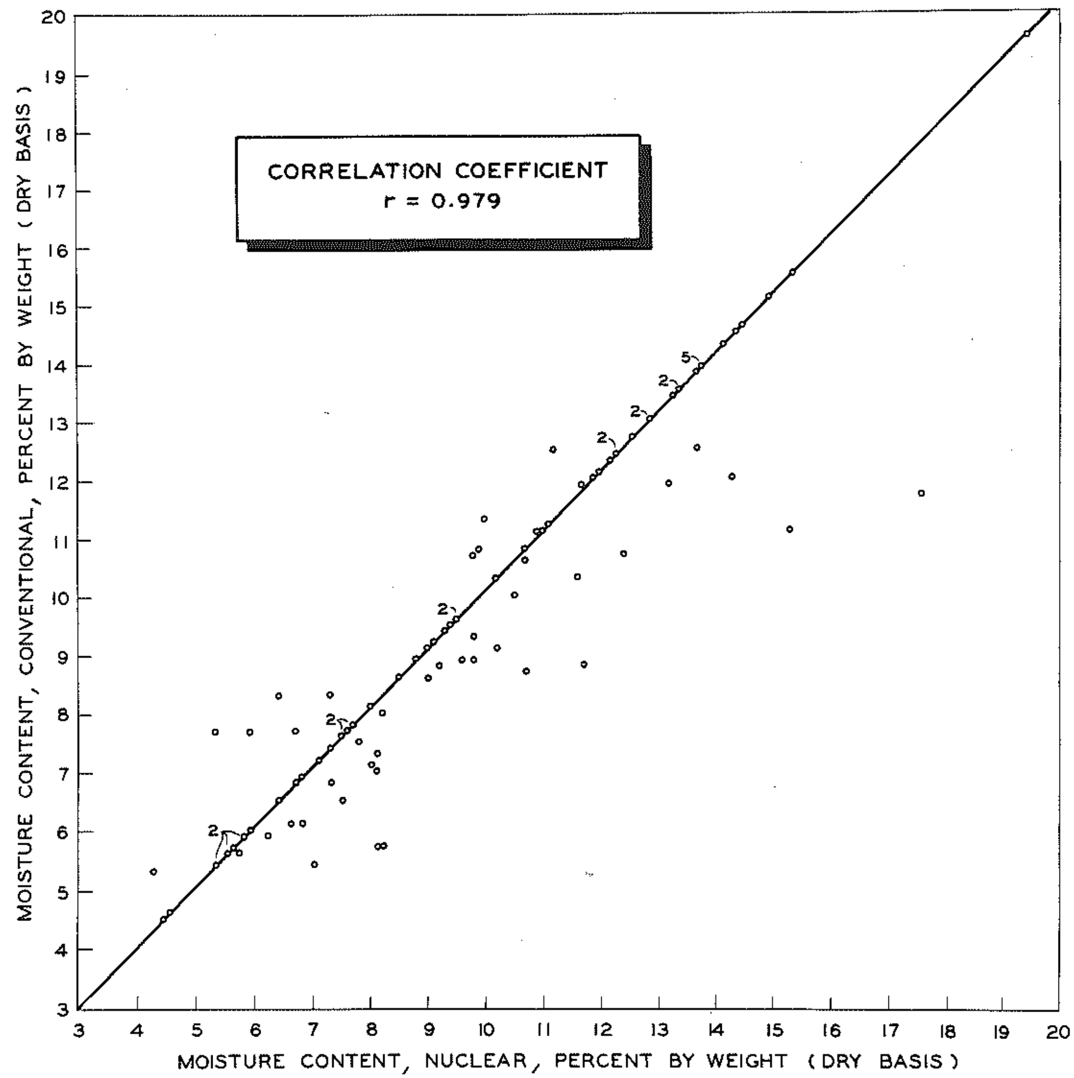


Figure 9. Conventional vs Nuclear Moisture.

The figures are scatter diagrams with the nuclear results plotted on the horizontal axis and the conventional results on the vertical axis. The correlation coefficient for the 159 density points shown in Figure 10 was 0.9447; that for the 172 moisture points in Figure 11 was 0.8903. This does not mean that the moisture portion of the gage is less accurate than the density portion, for a few moisture points were included in the analysis which would ordinarily be thrown out on the basis of Chauvenet's criterion (in this case more than about three times the standard deviation from the mean). These points were included because it is not known whether the corresponding conventional results were high because of sample loss by entrainment; or either high or low for some other reason such as small sample size, insufficient heating, etc.; or whether the gage itself was used incorrectly. It is known, however, that at the higher moisture contents, those soils which gave lower moisture contents by conventional tests than by the nuclear method had high percentages of clay or stone in most cases. The difficulty of driving all water out of such materials is well known. Conversely, the effect of sample loss through human error would be four or five times as great at the lower moisture contents as it would be at higher percentages of water. This could reasonably account for those points at the lower end of the graph which are higher by conventional test than by nuclear test.

All data used in Figures 10 and 11 are shown in Table 2 in the Appendix. Points not included in the density diagram in Figure 10 were discarded for the reasons listed in Table 2.

Speed of Operation

Although a one-minute count has proved satisfactory for either density or moisture measurement, this does not imply that one may determine the number of two-minute intervals in the working day and thus arrive at the number of nuclear tests which can be performed. The operator is still faced with the necessity of moving his equipment from place to place. This has proved to be the greatest single factor limiting the number of daily tests. At this writing, one crew has reported five conventional tests in addition to 35 nuclear tests for both density and moisture in a single day. By comparison, a total of eight conventional tests has been accepted as a satisfactory day's output, although the Department attempts to obtain more than this number with each crew.

Gage Stability and Reliability

As is often true of new devices, the Michigan gage has had its share of flaws and defects. During the first few weeks after the gages had been

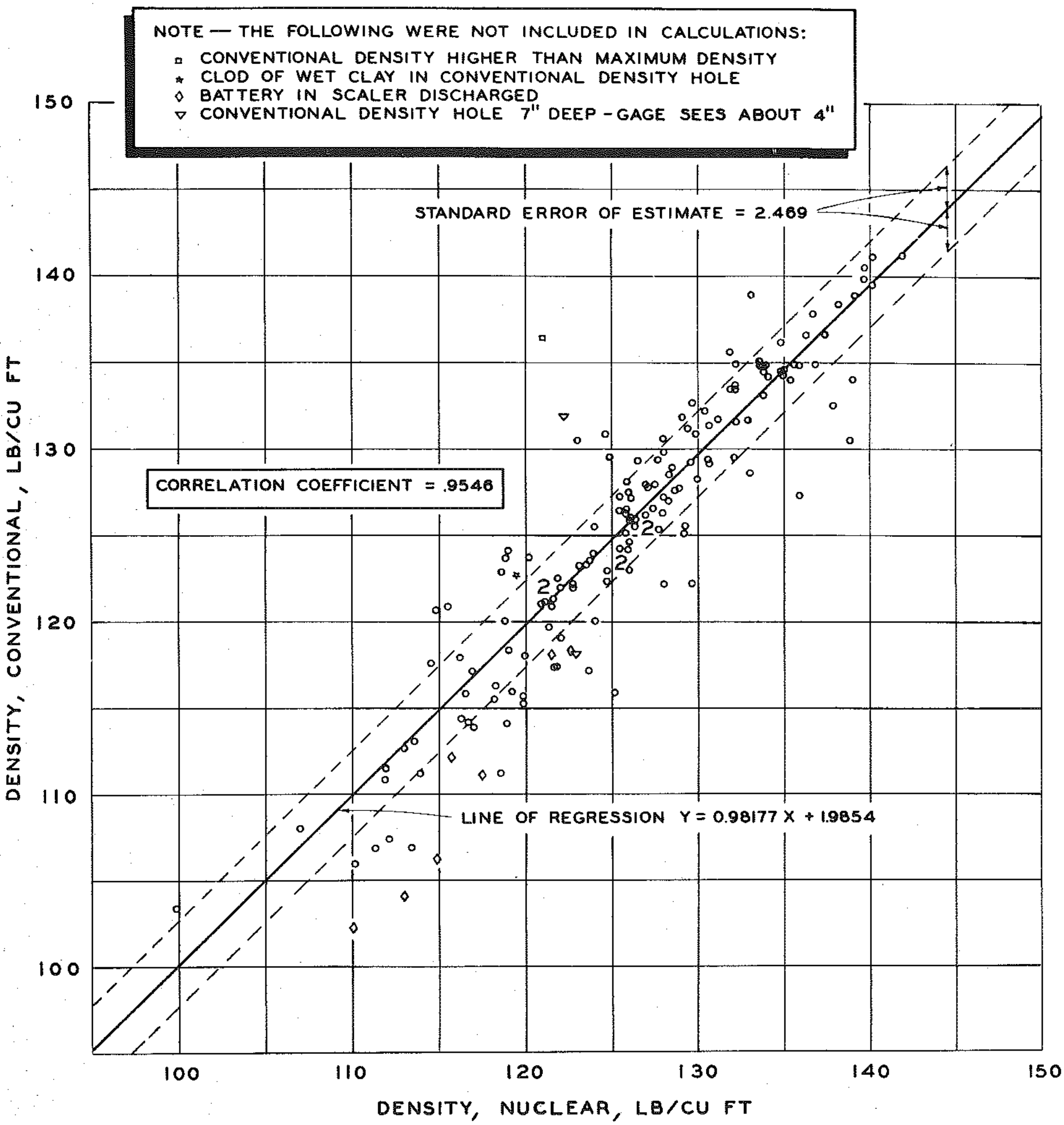


Figure 10. Nuclear vs Conventional Density
US-12 Relocation near Marshall, Michigan
(Individual determinations)

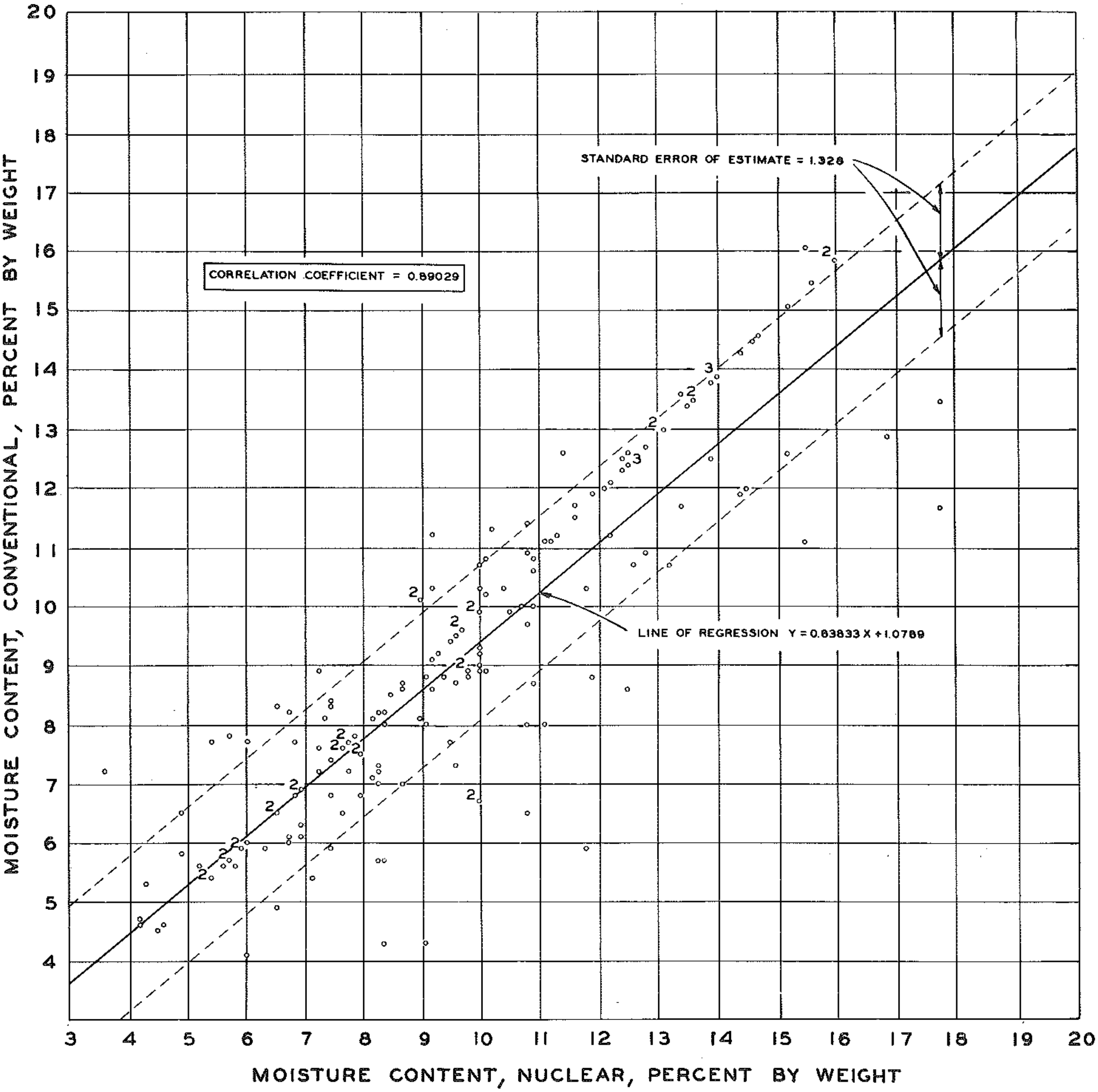


Figure 11. Nuclear vs Conventional Moisture
US-12 Relocation near Marshall, Michigan
(Individual determinations)

turned over to the density control crews, one technician was kept busy tracking down and eliminating imperfections. Some of these were electronic parts failures, and the parts were replaced. Others included incorrect scaler battery charging rates, which were easily adjusted; the opening of soldered electrical connections, which were resoldered; and cable damage caused by contractors' equipment running over the cable. In no case has any failure occurred which could not be promptly repaired, and no instance of fundamental inadequacy has arisen.

Variations Among Gages

Since it is next to impossible to manufacture two sources of radioactivity having precisely the same strength and geometry, each gage must be calibrated individually. This presents no problem, however, it being essentially a matter of determining the slopes of the curves. In practice, three or four good points are all that are required.

Operator Training

Density control personnel are trained to operate the Michigan gage in three days of intensive schooling. During this time the men are briefed in nuclear theory, particularly in its practical aspects including health and safety precautions, and each man operates the gage under direct supervision. At the conclusion of the course all participants are awarded a diploma patterned after that earned by members of the Oak Ridge isotope techniques courses. The response has been highly favorable.

Health and Safety

The United States Atomic Energy Commission defines permissible radiation levels in terms of whole-body radiation. It is physically impossible for a gage operator to receive an overdose of radiation within this definition without wrapping his body completely around the gage for an extended period of time. As a legal precaution, however, and because some tissues are more affected by radiation than others, gage operators are required to wear film badges and take biannual health examinations. Badges are available from a number of commercial firms, such as Tracerlab of Boston, and the medical examinations can be performed by any physician. A typical film badge is shown in Figure 12.

Regulatory Agencies

The United States Atomic Energy Commission possesses no regulatory power over naturally-occurring radioactive materials. Since radium falls in this category, the radium-beryllium source is generally considered to be outside the scope of AEC jurisdiction. All radioactive materials, however, come under the authority of most state health departments, and Michigan is no exception. The Michigan Department of Health requires copies of normal records including purchase date, ownership, intended use, etc., in addition to the results of periodic tests for possible leakage of the isotope from the sealed capsule. Relevant information and test results are furnished by the Research Laboratory Division.

In view of the complicated nature and many possible ramifications of radioactivity, it is felt very strongly that supervisory personnel should possess knowledge of this subject sufficient for AEC approval. Such knowledge can be obtained by taking the four-week radioisotope techniques course conducted by the Oak Ridge Institute of Nuclear Studies. The value of this course cannot be too highly stressed. Arrangements can be made through Dr. Ralph T. Overman, Chairman, ORINS, P.O. Box 117, Oak Ridge, Tennessee.

Figure 12. Typical film badge carried by operators using the Michigan Gage.

Summary

The Michigan State Highway Department has developed a nuclear gage which can be used to measure both the densities and the moisture contents of soils. The gage is a single instrument activated by a single radioactive source as opposed to other nuclear density and moisture gages which can estimate either density or moisture but not both. Moisture contents are determined directly in units of percent by weight without the necessity of knowing the density.

Over one thousand density and moisture determinations have been made by density control crews using these gages on regular construction projects in Michigan. Results on the whole have been encouraging, but the Department still considers use of the nuclear gages to be on an experimental basis.

Acknowledgments

The work described in this report was conducted as part of the Michigan State Highway Department research program vested in the Research Laboratory Division of the Office of Testing and Research, of which W. W. McLaughlin, Testing and Research Engineer, is the head.

The authors acknowledge the assistance of many members of the Laboratory staff, and of the following persons in particular: W. W. McLaughlin, and E. A. Finney, Director of the Research Laboratory Division, for their critical review; L. T. Oehler, Supervisor of the Laboratory Physical Research Section and staff for help on the statistical analyses of the data furnished by the Construction Division, Office of Engineering.

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APPENDIX

TABLE 1
CONVENTIONAL vs NUCLEAR RESULTS
ORIGINAL FIELD APPLICATION

POINT No.	MATERIAL	DENSITY, LB/FT^3 (wet basis)			MOISTURE % (dry basis)		
		Conventional	Nuclear	C-N	Conventional	Nuclear	C-N
1	Clay	138.0	129.4	8.6	11.5	10.9	0.6
2	"	137.0	135.5	1.5	8.8	9.7	-0.9
3	"	130.5	126.5	4.0	11.5	12.5	-1.0
4	"	128.2	125.0	3.2	17.8	15.0	2.8
5	"	121.9	127.0	-5.1	18.4	17.8	0.6
6	"	143.0	144.0	-1.0	10.4	10.4	0.0
7	"	108.1	114.0	-5.9	11.7	10.3	1.4
8	"	109.3	114.5	-5.2	11.3	10.3	1.0
9	"	110.5	118.0	-7.5	13.5	11.8	1.7
10	"	135.0	129.8	5.2	11.2	10.8	0.4
11	"	133.2	131.3	1.9	9.1	8.9	0.2
12	"	122.0	129.0	-7.0	18.5	15.6	2.9
13	"	134.0	133.0	1.0	10.0	10.8	-0.8
14	"	130.0	134.5	-4.5	13.8	11.5	2.3
15	"	116.0	119.0	-3.0	15.2	15.9	-0.7
16	"	135.0	129.5	5.5	15.7	13.1	2.6
17	"	135.0	130.0	5.0	13.8	13.2	0.6
18	"	128.0	135.0	-7.0	15.3	15.4	-0.1
		Mean deviation, 18 points	....	-0.57	....	....	0.76
19	Sand	119.0	122.0	-3.0	4.4	5.0	-0.6
20	"	111.1	110.0	1.1	4.3	3.5	0.8
21	"	104.2	107.0	-2.8	5.5	4.8	0.7
22	"	114.7	114.5	0.2	2.1	3.0	-0.9
23	"	107.8	111.3	-3.5	5.3	5.3	0.0
24	"	114.2	112.5	1.7	5.6	4.6	1.0
25	"	108.7	108.0	0.7	5.0	5.0	0.0
26	"	113.0	110.2	2.8	3.8	4.2	-0.4
27	"	104.6	101.3	3.3	5.0	3.6	1.4
28	"	107.2	103.3	3.9	7.3	7.3	0.0
29	"	113.2	112.3	0.9	7.9	7.8	0.1
30	"	121.3	121.0	0.3	14.2	12.9	1.3
31	"	125.3	118.8	6.5	14.3	13.3	1.0
32	"	125.0	123.5	1.5	12.0	12.5	-0.5
33	"	108.1	105.5	2.6	6.2	6.2	0.0
34	"	112.0	113.5	-1.5	6.2	6.2	0.0
35	"	107.2	115.0	-7.8	6.3	6.2	0.1
36	"	122.2	122.0	0.2	11.1	10.2	0.9
37	"	113.4	116.5	-3.1	7.5	6.2	1.3
38	"	116.2	114.5	1.7	7.6	7.2	0.4
39	"	100.5	100.0	0.5	2.1	2.4	-0.3
40	"	106.9	110.5	-3.6	6.6	6.8	-0.2
41	"	124.5	129.0	-4.5	14.0	13.0	1.0
		Mean deviation, 23 points	....	-0.13	....	....	0.32

TABLE 1 (continued)
CONVENTIONAL vs NUCLEAR RESULTS
ORIGINAL FIELD APPLICATION

POINT No.	MATERIAL	DENSITY, LB/FT^3 (wet basis)			MOISTURE % (dry basis)		
		Conventional	Nuclear	C-N	Conventional	Nuclear	C-N
42	Crushed Stone	138.0	143.0	-5.0	4.9	4.2	0.7
43	Foundry Sand	110.5	112.0	-1.5	8.2	8.0	0.2
44	" "	106.0	104.5	1.5	7.4	7.5	-0.1
45	" "	108.0	107.0	1.0	9.9	9.8	0.1
46	" "	106.0	105.0	1.0	9.8	9.8	0.0
47	23-A	144.4	142.5	1.9	3.8	4.0	-0.2
48	"	147.0	149.0	-2.0	7.3	7.2	0.1
49	"	132.0	130.0	2.0	5.2	5.0	0.2
50	"	134.5	134.5	0.0	5.1	5.0	0.1
51	22-A	144.0	141.5	2.5	8.1	8.9	-0.8
52	"	147.0	141.2	5.8	8.4	9.3	-0.9
53	Base Course	147.8	145.0	2.8	4.2	5.6	-1.4
54	" "	132.4	141.5	-9.1	4.6	5.8	-1.2
55	" "	150.2	150.0	0.2	6.0	6.9	-0.9
56	" "	142.8	136.5	6.3	6.1	6.9	-0.8
57	" "	143.9	143.5	0.4	7.5	8.1	-0.6
58	Selected Subbase	142.0	143.0	-1.0	3.4	4.6	-1.2
59	Sand and Selected Subbase	138.0	133.0	5.0	5.7	5.7	0.0
60	Clay	128.7	134.9	-6.2			
61	"	129.0	132.5	-3.5			
62	"	133.4	137.0	-3.6			
63	"	133.0	127.8	5.2			
64	Sand	126.5	121.0	5.5			
65	"	111.0	106.5	4.5			
66	Crushed Stone	134.0	130.5	3.5			
67	" "	134.0	131.0	3.0			
68	" "	130.0	134.5	-4.5			
69	" "	133.0	137.0	-4.0			
70	23-A	136.0	133.5	2.5			
		Mean deviation, 70 points		0.014			
71	Clay				12.7	12.6	0.1
72	Sand				15.1	13.6	1.6
73	Crushed Stone				4.0	4.2	-0.2
74	" "				4.2	4.5	-0.3
75	Foundry Sand				19.8	19.8	0.0
76	" "				15.4	16.1	-0.7
77	23-A				5.9	5.6	0.3
78	Selected Subbase				5.9	6.3	-0.4
79	" "				6.4	6.3	0.1
80	" "				6.4	6.5	-0.1
81	" "				6.4	6.1	0.3
		Mean deviation, 70 points					0.211

Table 2
Nuclear Density-Moisture Measurements
US 12 Relocation, East of Marshall, Control Section 13083

Test No.	Date	Contract	Location[1]	DENSITY (lb/cu ft)			MOISTURE (% dry weight)			Soil Type
				Conventional	Nuclear	C-N	Conventional	Nuclear	C-N	
1	3-18-59	C4RN	860+70	117.6	114.5	3.1	5.8	4.9	0.9	Sand - Clay
2	3-19-59	"	855+56	-----	107.5	---	9.1	9.1	0.0	"
3	"	"	854+00	121.0	120.9	0.1	12.4	12.4	0.0	"
4	"	"	860+75	122.2	128.0	-5.8	16.2	---	---	"
5	"	"	861+00	115.8	120.2	-4.4	7.6	7.6	0.0	"
6	"	"	861+00	105.2	100.8	4.4	5.3	4.3	1.0	"
7	3-20-59	"	854+00	103.4	99.8	3.6	8.3	7.4	0.9	"
8	"	"	855+50	136.4	121.0	15.4*	5.4	7.1	-1.7	"
9	"	"	859+00	123.7	118.8	4.9	6.8	7.4	-0.6	"
10	"	"	23 Mi Rd	120.8	115.5	5.3	---	8.2	---	"
11	"	"	23 Mi Rd	122.7	119.5	3.2	5.7	8.2	-2.5	"
12	3-21-59	"	23 Mi Rd	132.5	137.8	-5.3	14.6	14.6	0.0	"
13	3-23-59	"	860+50	134.0	139.0	-5.0	12.5	11.3	1.2	"
14	"	"	861+25	-----	120.8	---	19.6	19.6	0.0	"
15	"	"	861+00	-----	135.0	---	12.0	12.0	0.0	"
16	"	"	860+00	-----	123.0	---	11.1	11.0	0.1	"
17	"	"	844+00	122.5	121.8	0.7	10.0	10.6	-0.6	"
18	"	"	23 Mi Rd	131.8	122.2	9.6*	8.3	6.5	1.8	Sand
19	3-24-59	"	863+00	136.2	134.8	1.6	5.7	8.3	-2.1	"
20	"	"	845+00	130.5	138.8	-8.3	13.4	13.4	0.0	"
21	"	"	844+50	124.1	119.0	5.1	7.3	8.2	-0.9	"
22	"	"	844+00	-----	136.0	---	10.3	11.7	-1.4	"
23	3-25-59	"	863+00	138.9	133.1	5.8	8.6	9.1	-0.5	Clay - Sand
24	"	"	860+00	122.8	118.6	-4.2	10.7	12.5	-1.8	"
25	"	"	23 Mi Rd	-----	123.5	---	15.9	15.9	0.0	"
26	"	"	23 Mi Rd	115.3	119.8	-4.5	0.0	7.4	0.0	Sand
27	3-26-59	"	23 Mi Rd	129.4	126.5	2.9	13.5	13.5	0.0	"
28	"	"	23 Mi Rd	-----	128.4	---	12.4	12.4	0.0	Sand-Gravel-Clay
29	"	"	23 Mi Rd	123.7	120.2	3.5	8.0	8.3	-0.3	Sand
30	3-30-59	"	843+00	112.7	113.0	-0.3	15.9	15.9	0.0	Clay-Sand
31	"	"	843+00	-----	127.8	---	11.2	11.2	0.0	Sand
32	3-31-59	"	23 Mi Rd	-----	115.6	---	8.7	10.8	-2.1	Sand-Gravel
33	"	"	23 Mi Rd	116.3	118.3	-2.0	7.1	8.1	-1.0	"
34	"	"	23 Mi Rd	108.0	107.0	1.0	5.4	5.4	0.0	"
35	"	"	23 Mi Rd	113.9	117.0	-3.1	5.9	5.9	0.0	"
36	"	"	841+00	115.7	119.8	-4.1	9.2	9.2	0.0	"
37	4-6-59	"	23 Mi Rd	130.6	128.0	2.6	6.5	7.6	-1.1	Sand
38	"	"	23 Mi Rd	-----	118.4	---	6.8	6.8	0.0	"
39	"	"	23 Mi Rd	-----	120.5	---	7.8	7.8	0.0	"
40	"	"	23 Mi Rd	-----	127.1	---	7.6	7.6	0.0	"
41	"	"	23 Mi Rd	126.2	126.9	-0.7	9.3	9.9	-0.6	"
42	"	"	904+00	-----	125.8	---	9.6	9.6	0.0	Stony Sand - Clay
43	"	"	904+50	-----	115.3	---	11.1	11.1	0.0	Sand - Clay
44	"	"	905+25	-----	112.8	---	9.4	9.4	0.0	"
45	"	"	922+00	134.8	133.8	1.0	13.0	13.0	0.0	Sand - Clay pipe backfill
46	"	"	904+00	132.7	129.7	3.0	10.7	9.9	0.8	Sand - Clay
47	4-9-59	"	835+00	-----	109.3	---	5.6	5.6	0.0	Sand
48	"	"	835+50	122.2	122.6	-0.4	7.7	7.7	0.0	"
49	"	"	834+00	125.5	129.2	-3.7	8.1	8.1	0.0	"
50	"	"	833+25	-----	127.0	---	9.5	9.5	0.0	"
51	"	"	832+00	-----	115.6	---	6.0	6.0	0.0	"
52	"	"	23 Mi Rd	121.1	121.1	0.0	10.6	10.8	-0.2	"
53	"	"	23 Mi Rd	-----	117.0	---	7.7	7.7	0.0	"
54	"	"	23 Mi Rd	-----	117.0	---	7.7	5.4	2.3	"
55	"	"	23 Mi Rd	-----	113.4	---	7.7	6.8	0.9	"

[1] Bridge: 23 Mi Rd

* Not used in determining line of regression

Table 2 (continued)
Nuclear Density-Moisture Measurements
US 12 Relocation, East of Marshall, Control Section 13083

Test No.	Date	Contract	Location[1]	DENSITY (lb/cu ft)			MOISTURE (% dry weight)			Soil Type
				Conventional	Nuclear	C-N	Conventional	Nuclear	C-N	
56	4-9-59	C4RN	23 Mi Rd	-----	112.4	---	7.7	6.0	1.7	"
57	"	"	23 Mi Rd	111.5	111.9	-0.4	5.9	5.9	0.0	"
58	"	"	23 Mi Rd	-----	114.4	---	5.9	6.3	-0.4	"
59	"	"	23 Mi Rd	-----	123.9	---	10.8	10.0	0.8	"
60	4-10-59	"	863+00	106.3	114.8	-8.5*	5.7	5.7	0.0	"
61	"	"	862+30	104.1	113.0	-8.9*	6.9	6.9	0.0	"
62	"	"	861+75	102.3	110.1	-7.8*	5.4	5.4	0.0	"
63	"	"	860+75	111.1	117.0	-5.9*	4.6	4.6	0.0	"
64	"	"	860+00	118.1	121.5	-3.4*	7.5	7.9	-0.4	
65	"	"	860+30	112.1	115.7	-3.6*	5.7	5.7	0.0	"
66	"	"	861+50	118.3	122.6	-4.3*	6.5	6.5	0.0	"
67	4-13-59	"	856+00	133.5	131.9	1.6	11.9	13.3	-1.4	"
68	"	"	856+25	138.3	138.2	0.1	8.8	11.8	-3.0	"
69	"	"	855+00	139.5	140.2	-0.7	11.1	15.4	-4.3	Sand - Clay
70	"	"	855+75	140.3	139.7	0.6	11.7	17.7	-6.0	"
71	"	"	855+00	-----	130.5	---	14.3	14.3	0.0	"
72	"	"	1011+00	136.6	137.4	-0.8	13.0	13.0	0.0	"
73	"	"	1010+00	-----	134.8	---	12.3	12.3	0.0	"
74	"	"	1009+00	-----	130.9	---	12.7	12.7	0.0	"
75	"	"	985+00	-----	125.8	---	13.9	13.9	0.0	"
76	4-14-59	"	1010+50	127.9	127.0	0.9	8.9	9.9	-1.0	Sandy Gravel
77	"	"	1010+00	128.6	133.0	-4.4	---	11.3	---	"
78	"	"	1009+50	134.0	135.4	-1.4	12.1	12.1	0.0	"
79	"	"	903+00	131.4	130.7	0.7	---	9.6	---	Very Stony Material
80	"	"	903+50	135.6	131.8	3.8	---	12.8	---	Very Stony Material
81	"	"	905+00	129.5	124.9	4.6	---	11.5	---	Very Stony Material
82	4-15-59	"	23 Mi Rd	129.4	130.6	-1.2	11.9	11.8	0.1	Clay
83	"	"	24 Mi Rd	129.5	132.1	-2.6	10.3	10.3	0.0	Sand - Gravel
84	"	"	26 Mi Rd	-----	129.8	---	13.5	13.5	0.0	Sand
85	"	"	24 Mi Rd	-----	131.8	---	13.9	13.9	0.0	"
86	"	"	820+00	132.2	131.4	0.8	9.1	10.3	-1.2	Sand - Gravel
87	4-16-59	"	1003+00	120.0	118.7	1.3	9.6	9.6	0.0	Sand
88	"	"	26 Mi Rd Ramp E	134.8	135.9	-1.1	12.5	13.8	-1.3	Sandy Clay
89	"	"	26 Mi Rd Ramp G	-----	133.9	---	13.9	13.9	0.0	"
90	"	"	24 Mi Rd	-----	124.9	---	10.8	10.8	0.0	Sand - Gravel
91	"	"	24 Mi Rd	-----	123.7	---	8.6	8.6	0.0	Sand
92	"	"	24 Mi Rd	-----	115.0	---	4.5	4.5	0.0	"
93	"	"	24 Mi Rd	-----	119.2	---	7.2	7.2	0.0	"
94	4-17-59	"	26 Mi Rd Ramp E	122.3	124.7	-2.4	11.3	10.1	1.2	Sandy Clay
95	"	"	24 Mi Rd	120.6	114.8	5.8	8.8	9.3	-0.5	Sand
96	"	"	24 Mi Rd	126.3	125.8	0.5	---	9.8	---	"
97	"	"	24 Mi Rd	113.0	113.6	-0.6	---	7.8	---	"
98	4-18-59	"	24 Mi Rd	131.2	129.4	1.8	8.9	9.7	-0.8	Sand - Gravel
99	"	"	1003+00	-----	131.1	---	14.5	14.5	0.0	Sandy Clay
100	"	"	830+00	133.7	132.2	1.5	15.5	15.5	0.0	Sandy Clay Gravel
101	4-20-59	"	906+00	126.2	127.9	-1.7	7.4	7.4	0.0	Sand
102	"	"	26 Mi Rd Ramp H	134.9	132.2	2.7	13.8	13.8	0.0	Sand - Clay - Stone
103	"	"	828+00	106.9	113.4	-6.5	6.1	6.7	-0.6	Sand
104	"	"	827+00	-----	118.4	---	6.1	6.9	-0.8	"
105	4-21-59	"	1007+75	122.2	129.7	-7.5	5.6	5.8	-0.2	"
106	"	"	1006+75	125.1	129.3	-4.2	---	9.5	---	"
107	"	"	1006+50	129.3	129.6	-0.3	---	12.3	---	"
108	"	"	24 Mi Rd	134.8	133.6	1.2	7.0	8.2	-1.2	"
109	4-22-59	"	26 Mi Rd Ramp H	137.8	136.7	1.1	12.0	14.4	-2.4	Sand - Clay
110	"	"	26 Mi Rd Ramp H	-----	133.0	---	15.1	15.1	0.0	"

[1] Bridge: 23 Mi Rd, 24 Mi Rd
Interchange: 26 Mi Rd

* Not used in determining line of regression

Table 2 (continued)
Nuclear Density-Moisture Measurements
US 12 Relocation, East of Marshall, Control Section 13083

Test No.	Date	Contract	Location[1]	DENSITY (lb/cu ft)			MOISTURE (% dry weight)			Soil Type
				Conventional	Nuclear	C-N	Conventional	Nuclear	C-N	
111	4-22-59	C4RN	829+00	-----	127.6	---	9.9	9.9	0.0	Sand - Gravel - Silt
112	"	"	26 Mi Rd Ramp H	129.8	128.0	1.8	11.5	11.5	0.0	Sandy Clay
113	4-23-59	"	844+50	134.3	134.9	-0.6	11.7	13.3	-1.6	Sand
114	"	"	842+00	-----	118.7	---	7.0	8.6	-1.6	"
115	"	"	1003+00	124.2	125.4	-1.2	---	11.2	---	Sand
116	"	"	924+00	129.2	130.7	-1.5	---	6.2	---	"
117	4-24-59	"	903+00	130.5	128.0	2.5	9.2	9.9	-0.7	"
118	"	"	26 Mi Rd	134.2	134.1	0.1	---	12.9	---	Clay
119	"	"	1005+00	136.3	136.6	-0.3	---	12.7	---	Sandy clay
120	4-25-59	"	1086+50	130.8	129.7	1.1	---	10.8	---	Sand
121	"	"	26 Mi Rd	111.2	118.6	-7.4	---	10.7	---	"
122	4-27-59	"	1095+00	115.8	116.5	-0.7	6.5	6.5	0.0	"
123	"	"	896+50	141.2	140.2	1.0	---	6.7	---	Stony Sand
124	5-4-59	"	1097+50	127.2	128.0	-0.8	16.1	15.4	0.7	Sand
125	"	"	1091+00	127.7	128.9	-1.2	9.7	10.7	-1.0	"
126	"	"	1079+00	119.7	121.3	-1.6	6.9	6.9	0.0	"
127	5-5-59	"	1080+50	134.5	134.8	-0.3	12.5	12.3	0.2	Sand - Gravel
128	"	"	1089+00	118.2	122.8	-4.6*	---	9.1	---	"
129	5-6-59	"	1003+75	133.1	131.8	1.3	8.9	9.7	-0.8	Sandy Clay - Silt
130	"	"	1080+50	127.0	128.3	-1.3	7.2	8.2	-1.0	Sand
131	5-7-59	"	1002+50	135.1	133.6	1.5	12.4	12.4	0.0	Sandy Clay
132	"	"	1217+00	118.0	119.9	-1.9	7.6	9.4	-1.8	Sand
133	"	"	1008+00	126.5	125.8	0.7	---	5.2	---	Sand - Gravel
134	5-8-59	"	1218+50	125.5	126.3	-0.8	7.6	7.2	0.4	Sand
135	"	"	1079+00	126.0	126.1	-0.1	8.2	8.2	0.0	"
136	5-12-59	"	27 Mi Rd N	118.0	122.0	-4.0	9.0	9.9	-0.9	"
137	"	C2RN	Partello Rd Ramp A	122.9	126.0	-3.1	---	8.2	---	Sand - Clay - Stones
138	5-13-59	C4RN	27 Mi Rd N	115.5	118.2	-2.7	10.2	10.0	0.2	Sand
139	"	C2RN	Partello Rd Ramp A	125.5	124.0	1.5	---	9.5	---	"
140	5-14-59	C4RN	29 Mi Rd	134.9	136.8	-1.9	10.9	12.7	-1.8	Clay
141	"	"	27 Mi Rd N	125.1	125.8	-0.7	---	11.3	---	Sand
142	5-15-59	C2RN	Partello Rd Ramp A	121.9	122.0	-0.1	8.2	8.3	-0.1	"
143	"	"	Partello Rd Ramp C & D	123.2	123.1	0.1	---	9.3	---	"
144	5-16-59	"	Partello Rd Ramp C & D	114.4	116.3	-1.9	---	9.3	---	"
145	"	"	Partello Rd Ramp A	122.9	126.0	-3.1	---	11.2	---	"
146	5-18-59	"	Partello Rd Ramp A	106.8	111.3	-4.5	10.3	9.9	0.4	"
147	"	"	18 1/2 Mi Rd	139.8	139.7	0.1	---	15.4	---	Sand - Clay
148	"	"	Partello Rd Ramp A	106.0	110.2	-4.2	---	8.9	---	Sand
149	5-19-59	"	Partello Rd Ramp A	140.5	139.7	0.8	8.6	12.4	-3.8	Sand - Silt
150	"	"	Partello Rd Ramp C & D	120.0	124.0	-4.0	---	12.4	---	Sand
151	5-20-59	"	Partello Rd Ramp C & D	117.2	123.7	-6.5*	10.7	13.1	-2.4	"
152	5-22-59	"	Partello Rd Ramp C & D	127.3	135.9	-8.6	13.5	17.7	-4.2	"
153	"	"	Partello Rd Ramp C & D	128.5	128.4	0.1	---	---	---	----
154	5-26-59	"	18 1/2 Mi Rd	115.9	119.2	-3.3	11.2	9.1	2.1	Sand
155	6-10-59	C1RN	717+00	138.9	139.1	-0.2	12.6	12.4	0.2	Sand - Clay
156	"	"	22 1/2 Mi Rd NE Ramp	134.6	135.0	-0.4	10.9	10.7	0.2	---
157	6-11-59	"	20 Mi Rd	114.2	116.7	-2.5	8.0	10.7	-2.7	Clay - Stone
158	6-13-59	C4RN	29 Mi Rd Svc Rd N	127.8	127.1	0.7	6.0	6.7	-0.7	Sand - Stone
159	6-15-59	C1RN	648+00	126.4	125.4	1.0	8.7	9.5	-0.8	Sand - Clay - Gravel
160	6-17-59	"	810+00	134.5	133.8	0.7	13.6	13.3	0.3	Sand - Clay
161	"	C4RN	26 Mi Rd	123.3	123.5	-0.2	5.9	11.7	-5.8	----
162	6-18-59	"	26 Mi Rd	141.2	141.9	-0.7	11.2	12.1	-0.9	Sand - Gravel
163	"	C1RN	22 1/2 Mi Rd NE Ramp	134.9	135.6	-0.7	11.7	11.5	0.2	Sand - Clay
164	6-19-59	"	22 1/2 Mi Rd	117.1	116.9	0.2	4.3	8.3	-4.0	Sand
165	"	C4RN	26 Mi Rd SW Ramp	117.9	116.2	1.7	4.1	6.0	-1.9	"

[1] Bridges: 18 1-2 Mi Rd, 20 Mi Rd
Interchanges: Partello Rd (19 Mi Rd), 22 1-2 Mi Rd, 26 Mi Rd, 27 Mi Rd, 29 Mi Rd

* Not used in determining line of regression

Table 2 (continued)
Nuclear Density-Moisture Measurements
US 12 Relocation, East of Marshall, Control Section 13083

Test No.	Date	Contract	Location [1]	DENSITY (lb/cu ft)			MOISTURE (% dry weight)			Soil Type
				Conventional	Nuclear	C-N	Conventional	Nuclear	C-N	
166	6-20-59	C1RN	810+00	134.8	133.9	0.9	12.9	16.8	-4.1	Clay
167	"	"	22 1/2 Mi Rd	127.2	125.4	1.8	4.9	6.5	-1.6	Sand
168	6-30-59	"	707+50	127.1	126.1	1.0	6.5	4.9	1.6	Stony Sand
169	"	"	711+00	121.9	122.7	-0.8	7.2	3.6	3.6	----
170	"	C4RN	26 Mi Rd SW Ramp	125.3	127.7	-2.4	10.1	8.9	1.2	Sand
171	7-10-59	C2RN	Partello Rd - S	127.9	127.0	0.9	7.5	7.9	-0.4	"
172	"	"	18 1/2 Mi Rd	131.6	132.2	-0.6	9.9	9.9	0.0	---
173	"	"	Partello Rd - N	-----	-----	---	9.9	10.4	-0.5	---
174	"	"	Partello Rd - W	131.7	131.2	0.5	8.0	9.0	-1.0	---
175	"	C4RN	26 Mi Rd SW Ramp	125.3	127.7	-2.4	10.1	8.9	1.2	Sand
176	7-22-59	C2RN		132.1	132.0	0.1				
177	"	"		134.8	133.5	1.3				
178	"	"		129.7	123.0	6.7				
179	"	"		123.8	124.5	-0.7				
180	"	"		131.0	129.8	1.2				
181	"	"		120.7	120.0	0.7				
182	"	"		115.1	114.0	1.1				
183	"	"		133.7	131.5	2.2				
184	7-30-59	C1RN	405+00**	117.4	121.8	-4.4	8.7	8.6	0.1	---
185	"	C3RN	17 1/2 Mi Rd N	114.1	113.9	0.2	5.6	5.2	0.4	Sand
186	7-31-59	"	17 1/2 Mi Rd S	122.9	124.7	-1.8	7.8	5.7	2.1	Sand - Stone
187	8-3-59	C1RN	754+00	121.3	121.6	-0.3	6.7	9.9	-3.2	---
188	8-4-59	"	20 Mi Rd N	107.4	112.1	-4.7	6.4	10.7	-4.3	---
189	"	C2RN	659+00	133.5	132.2	1.3	4.3	9.0	-4.7	---
190	"	C1RN	730+00	125.9	126.4	-0.5	8.9	10.0	-1.1	---
191	8-5-59	"	726+00	111.2	113.9	-2.7	5.9	7.4	-1.5	Sand Subbase
192	"	"	712+00	128.1	125.9	2.2	8.4	7.4	1.0	"
193	"	"	691+00	126.5	127.4	-0.9	7.3	9.5	-2.2	"
194	8-6-59	"	681+00	127.5	126.0	1.5	10.0	10.8	-0.8	"
195	8-7-59	C4RN	868+00	131.8	129.1	2.7	8.0	11.0	-3.0	"
196	8-8-59	C1RN	693+00	123.9	123.9	0.0	12.6	15.1	-2.5	"
197	8-10-59	"	726+00	130.8	129.8	1.0	---	8.4	---	"
198	8-11-59	"	771+00	127.6	128.7	-1.1	11.4	10.7	0.7	"
199	"	"	776+00	129.4	127.6	1.8	8.5	8.4	0.1	"
200	"	"	649+00	110.8	111.8	-1.0	4.7	4.2	0.5	"
201	"	"	788+00	120.8	121.5	-0.7	4.6	4.2	0.4	"
202	8-13-59	"	754+00	121.3	121.6	-0.3	6.7	9.9	-3.2	"
203	8-14-59	"	780+00	125.9	126.0	-0.1	8.1	8.9	-0.8	"
204	"	"	796+00	123.5	123.7	-0.2	8.2	6.7	1.5	"
205	8-18-59	C4RN	850+00	124.6	126.0	-1.4	8.8	9.7	-0.9	"
206	8-19-59	"	863+00	117.3	116.7	0.6	6.3	6.9	-0.6	"
207	8-21-59	"	900+00	128.8	128.5	0.3	8.9	7.2	1.7	"
208	"	"	918+00	131.7	132.9	-1.2	8.1	7.3	0.8	"
209	8-22-59	"	936+00	124.1	125.9	-1.8	7.2	7.7	-0.5	"
210	"	"	946+00	118.3	119.0	-0.7	9.8	10.0	-0.2	"
211	8-24-59	"	960+00	128.3	130.0	-1.7	6.8	7.9	-1.1	"

[1] Bridges: 17 1-2 Mi Rd, 20 Mi Rd
Interchanges: Partello Rd (19 Mi Rd), 22 1-2 Mi Rd, 26 Mi Rd

** Control section 13082, Marshall west

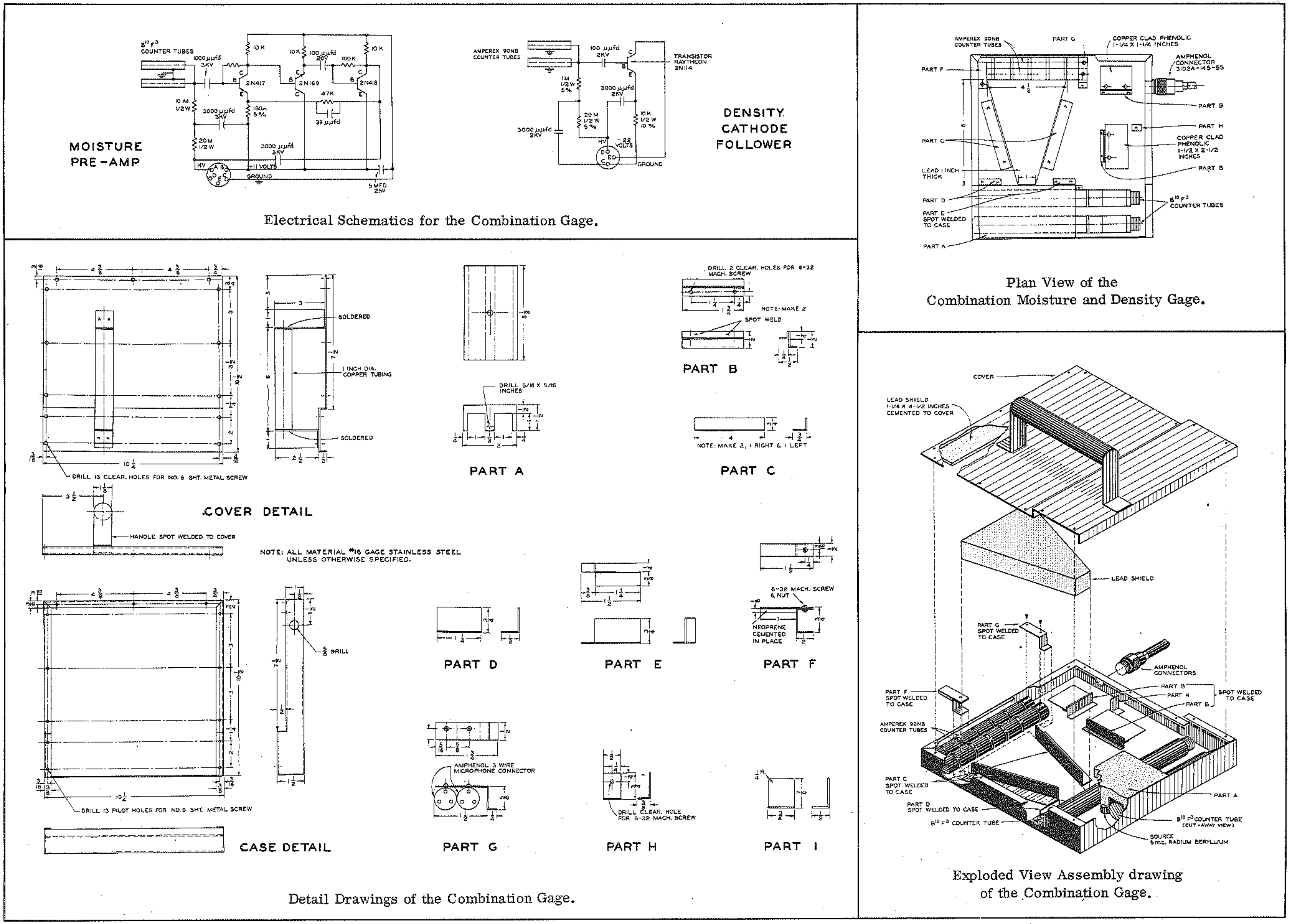

Figure 13. Engineering Drawing of the Combination Gage.