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REPORT **MR90-1**

Field Evaluation of Nuclear Moisture-Density Gauges

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FIELD EVALUATION OF NUCLEAR MOISTURE-DENSITY GAUGES

REPORT MR90-1

Prepared By

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

DIVISION OF MATERIALS AND RESEARCH

FINAL REPORT

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ABSTRACT

Results obtained from testing seven different models of nuclear moisture-density gauges from four different manufacturers were compared and were also correlated to those obtained by a balloon type volume device at twenty test sites chosen on active construction sites throughout the state. Eleven of the test sites were chosen to evaluate soil subgrade properties. These sites represented nine different soil types. The remaining nine sites were selected for base testing, representing five graded aggregate types.

A gauge employing the air gap/backscatter method seemed to be greatly affected by surface conditions. Results obtained using this method were not consistent with those obtained with gauges employing the direct transmission method or the balloon type volume device.

The test results from conventional type direct transmission gauges manufactured by Campbell Pacific Nuclear (CPN Corp.), Humboldt Scientific and Troxler Electronics were analyzed statistically. Results of the analysis indicated the gauges were consistent with one another and readings were highly repeatable.

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INTRODUCTION

There have been an increasing number of nuclear moisture-density gauges becoming available. Since 1974, the Missouri Highway and Transportation Department has allowed only Troxler 3401 series gauges to be used for moisture and density testing of soils and bases. This study has been conducted to evaluate the other nuclear moisture-density gauges now available. This will allow competitive bidding for nuclear gauges on future purchases.

Specific objectives of this study were:

1. Determine the available sources for nuclear moisture-density gauges.

2. Obtain several models of gauges from their respective manufacturers.

3. Conduct comparative field testing in a wide range of soil and stone aggregate types at active construction sites throughout the state.

4. Recommend acceptance or rejection of the available models of nuclear moisture-density gauges for use in compaction control on state highway projects.

IMPLEMENTATION

The nuclear moisture-density gauges manufactured by CPN Corporation, Humboldt Scientific, and Troxler Electronics are recommended for use by the department. One of these gauges should be selected by the competitive bidding process for use in compaction control of earthwork and graded aggregate base.

The direct readout type gauges should be given preference, since the simplicity of operation and the time saved in obtaining needed test results will justify the slightly higher cost. Also, direct readout eliminates the possibility that errors might be introduced in calculations and interpretation of calibration charts. Selection of the top of the line models manufactured by CPN and Troxler is not justified, since many of the available features would probably not be utilized by the Department.

The following gauges are recommended:

CPN Model MC-1DR

Humboldt Model 5001P

Troxler Model 3411

Troxler Model 3430*

*A prototype of this gauge was evaluated. It is not currently available, but may be very soon.

TEST EQUIPMENT

The following nuclear moisture density gauges were provided by their respective manufacturer for use in this evaluation.

CPN Model MC-1DR

CPN Model MC-3

Humboldt Model 5001P

Troxler Model 3430

Troxler Model 3440

Seaman Model C-75A

In addition, a Troxler Model 3401B currently owned by the Department was included in the evaluation for comparison. All gauges were calibrated immediately prior to the evaluation. Retail prices for the nuclear gauges currently on the market are shown in Table 1. These figures should only be used as estimates, since actual bid prices can vary greatly from the retail prices.

Excepting the Seaman Model C-75A, all of the gauges tested (and all other known gauges except those manufactured by Seaman Nuclear) use the conventional configuration of a source rod which protrudes from the gauge and detector tubes which are located in the base of the gauge. The gauges manufactured by Seaman Nuclear Corporation differ in that the source is located within the base of the gauge during testing. The detector tubes for the Seaman gauge are also located in the base of the instrument for use in the

backscatter and air gap/backscatter modes. An optional external detector tube was provided with the Seaman Model C-75A for use in the direct transmission mode during our evaluation.

A Soiltest Model CN-980 Volumeasure, a small water balloon device equipped with a pressure gauge, was also used at several of the test sites for comparison purposes.

TEST SITES

Twenty test sites were chosen on active construction sites throughout the state. Figure 1 is a map of Missouri showing the locations selected for testing. Site selection was determined primarily by material type. As many different types of soils and bases as practical were tested.

Eleven test sites were chosen to evaluate soil subgrade properties. These sites represented nine different soil types. Likewise, nine sites were selected for base testing, representing five different aggregate types. Table 2 describes the soil or base type at each test site, and shows the average wet density and moisture content calculated from the nuclear gauge results.

TEST PROCEDURES

A 200-foot long test section was selected at each of the 20 test sites. Four test locations were selected on each test sections spaced at 50-foot intervals. Each test location was carefully prepared using a scraper plate to provide a smooth, level surface for the gauges. A four-minute standard count was taken for each gauge at each test site using the manufacturer's recommendations. No gauge was within 50 feet of any other radioactive source or any structure during testing. Moisture and density tests were taken using the air gap/backscatter method with the Seaman C-75A gauge since this method was recommended by the manufacturer. The access hole was then drilled at each test location using the drill rod provided with the Humboldt gauge and the remainder of testing was conducted using the direct transmission method. All tests with the CPN, Humboldt, and Troxler gauges were taken in the same access holes in the same orientation. The hole was enlarged using the Seaman drill rod before direct transmission testing with the Seaman C-75A gauge. Four one-minute tests were taken with each gauge at each test location, resulting in a total of 16 tests per gauge at each of the 20 test sites.

Source rod depth (or detector tube depth with the Seaman gauge) was set at six inches for all soil tests and four inches for all graded aggregate testing. Care was

taken to ensure the same general volume of material was tested by each gauge.

After nuclear testing was completed, 16 of the 20 sites were tested using the rubber-balloon method. The volume of material dug for these tests was, as near as practical, approximately the same as that tested by the nuclear gauge. Material from the holes was sealed in plastic bags and returned to the lab for weighing and drying.

ANALYSIS OF TEST RESULTS

Wet density, percent moisture, density counts and moisture counts were recorded in the field for each nuclear test. In addition, results from a balloon type volume device were recorded at 16 of the 20 test sites (See Table 3). Wet densities and moisture contents were then calculated from the volumeasure samples.

The precision of each gauge at each test location was calculated using a one-way-anova computer program. The results of this analysis indicate that all the gauges, except the Seaman gauge in air gap/backscatter mode, have an index of precision of less than one percent for moisture and about one pound per cubic foot or less wet density. (See Tables 4 and 5). This degree of precision indicates excellent repeatability of all gauges in the direct transmission configuration.

Since there is currently a standard test method (MHTD T35-4-84) for calculating a moisture correction factor for nuclear gauges, this test for precision is all that was necessary for moisture testing. After a correction factor is used, all the gauges tested would yield percent moisture results with an accuracy of one percent or less. This is more than adequate for the department's use.

The department does not currently use a correction factor for nuclear wet density testing. Therefore, a test for the accuracy of density results was required. Since the

balloon method for density determination has its own associated errors and a precision far less than the nuclear gauges, comparing gauge readings directly with results from this method is not feasible. Standard deviations were therefore calculated based on average wet density from all the gauges plus the balloon test results. These results are found in Table 6. Average standard deviations of approximately three pounds per cubic foot or less were found for all gauges except the Seaman C-75-A (in both air gap/backscatter and direct transmission mode) and the Troxler Model 3401B. This degree of accuracy is acceptable for density testing for the department. It was felt that the results of the analysis may have been too heavily weighted by the results from the Seaman gauge and volumeasure; therefore, the standard deviation was recalculated based on an average from only the conventional direct transmission gauges (CPN, Humboldt, and Troxler gauges). As shown in Table 7, this analysis yielded an excellent correlation between these gauges and an accuracy of approximately one to two pounds per cubic foot in most cases.

The only conventional direct transmission gauge that failed to meet this degree of accuracy was the Troxler Model 3401B. This gauge was calibrated just prior to the evaluation and showed excellent repeatability during field testing. The lower degree of accuracy may be due to an

error in calibration rather than a fundamental difference between it and the other conventional gauges.

Results obtained from the Seaman nuclear gauge seemed to be significantly affected by the surface conditions at the test locations. This conclusion is logical since the density results obtained using a nuclear gauge are more greatly affected by the material conditions nearest the radioactive source. The density of the material four to six inches below the surface (the closest material to the source when using a conventional direct transmission gauge) should be more comparable to the average density of the material tested than the conditions at the surface (the material nearest the source for the Seaman's gauge). Also, surface preparation is less critical when using a conventional direct transmission gauge, for the same reasons.

OPERATOR PREFERENCE

After the field evaluation had been completed, a survey of the gauge operators involved in the evaluation was conducted. The survey asked for comments concerning the ease of use, display, keypad, features, maintenance, documentation, and learning ease of each of the gauges. The following paragraphs give a brief description of each of the gauges evaluated and comments about the idiosyncrasies of each gauge. Figures 2 through 8 are pictures of the gauges that were evaluated.

Seaman Model C-75-A

The Seaman Nuclear Corporation is the only manufacturer that recommends testing by the air gap/backscatter method. While the gauge was fairly simple to operate, greater site preparation (a smoother surface) was necessary to obtain good results. Even then, test results are greatly affected by the surface density and moisture and were inconsistent with test results from the other gauges.

The Seaman C-75-A also includes an optional external detector tube for direct transmission tests. The results obtained using the direct transmission method were more consistent with those from the other gauges evaluated; however, the surface conditions still appeared to have a significant effect on the results. The Seaman gauge requires a larger access hole than the other gauges, and the hole must be very close to perpendicular with the surface

for correct detector tube placement. The gauge design suggests that the direct transmission option was an add-on feature not considered during the original design of the gauge. The detector tube was described as "fairly fragile" and must be carried in a separate case from the gauge. The durability of this gauge does not appear to be comparable to the extremely rugged design of the other gauges evaluated.

Humboldt 5001P

Dedicated keys for each function make testing with the Humboldt 5001P straightforward and simple. The gauge has a one-line depth display and a one-line data display. The numbers are large and easy to read even in direct sunlight. The gauge requires two key presses for all inputs (maximum density, etc.) but only one key press is required to obtain test data values.

The gauge uses six standard "AA" size alkaline batteries as a power source. The batteries are easily field replaceable and the manufacturer claims an 800-hour work period between battery replacements is typical. Accessories included with the gauge are a canvas accessory bag, a drill guide/scrapper plate, a drill rod, extraction tool and a four-pound hammer.

Results obtained using the Humboldt 5001P were very consistent with those obtained from the other direct transmission gauges and are highly repeatable.

CPN Model MC-1DR

This gauge was found to be very simple to operate. With just three keys, an easy to read two-line display and an automatic source rod depth indicator. This gauge does not have a provision for entering a maximum density value for calculating the percent compaction, but does provide direct readout of the wet density, moisture density, dry density, moisture content, moisture count, density count and standard count.

The accessory kit provided with the gauge includes tools for the removal of the four electronic assemblies which are field replaceable. The power source is a welded pack of six "D" size alkaline batteries. CPN claims these will provide power for a full year of testing. There are also provisions for using a nine volt transistor radio battery for emergencies which should provide power for up to 1000 readings according to CPN.

CPN Model MC-3

This is CPN's "top of the line" model. It features a multi-line display, memory storage for 128 tests, serial interface for a printer, operator-selectable time or precision of test, programmable maximum values from lab tests, rechargeable nicad batteries (600 tests/charge), test modes for thin layer calculations and trench wall correction, and self calibration. While these features are certainly impressive, they make operating the gauge much more difficult than the MC-1DR. The multi-line display is

very difficult to read in direct sunlight. Multiple key presses were necessary to obtain the data values recorded for our survey (wet density, percent moisture, moisture count, and density count). These routines were fairly difficult to learn.

Troxler 3440

This is Troxler's "top of the line" model. It features automatic source rod depth sensing and a multi-line display. The keypad is multi-functional, but is well organized making testing moderately easy. The multi-line display allows viewing of several lines of data at once, but is fairly difficult to read in direct sunlight.

The Troxler 3440 has many advanced features including storage for over 450 readings, an internal stat test, drift test, recover erase, auto station, special calibration, nomograph mode (for thin lifts), precision check, set units, battery monitor and source decay monitor. The gauge also has a serial port for connecting a computer or printer to transfer test results.

A technical problem was experienced with the first gauge provided by Troxler that may have resulted from moisture in the gauge from exposure to light rain. Troxler quickly replaced the gauge with another loaner and no more problems were experienced.

The 3440 has rechargeable nicad battery packs which should provide for about eight weeks of testing. Also

included with the gauge are battery holders to allow use of standard "D" size alkaline batteries.

Troxler Model 3430

This gauge was a prototype that was not yet available for purchase when we conducted our evaluation, but should be available soon. The gauge was very simple to operate, with a 10-key pad and two-line display. It was easy to start tests and the up and down arrows on the keyboard made it simple to scroll through test results.

While this gauge was simple to operate, it also included some advanced features. The maximum density can be entered and percent compaction will be displayed after the test. Other special features include recall of last readings, automatic offset for moisture and trench correction, stat and drift tests, special calibration for materials with different densities, specific gravity entry, and display of percent air voids or void ratio, and access to calibration constants to allow recalibration. This gauge has the same battery packs as the Model 3440.

This gauge seems to be a good compromise between the very basic, easy to operate gauges and the advanced feature gauges.

Troxler Model 3401B

This is the gauge currently being used by the department. The gauge is very simple to operate with a one-line display, two rotary switches and a start button.

The 3401B has virtually no extra features. The display has no direct readout capability but indicates only density and moisture counts. Data must be reduced using a calculator and calibration chart. Approximately three or four times the actual testing time is required to calculate the moisture content, wet density, and dry density.

Even though the 3401B gauge used was recalibrated prior to the evaluation, densities and moistures tended to be higher than those obtained from the other gauges. Repeatability of test results was excellent with this gauge as well as all the other standard configuration (source in the hole) direct transmission gauges.

Troxler Model 3411

This gauge was not available for our evaluation, but probably deserves mention. The Model 3411 is the next step up from the gauge currently used by the department. It has the same source/detector configuration as the 3401B, but has direct readout and moisture correction factor adjustment. This gauge has been specified by the Arkansas DOT for some time.

While this gauge would probably be acceptable for use by the department, discussions with representatives of Troxler Electronics indicate that this model will be phased out and replaced with the Model 3430 as it becomes available. They also indicated they would be pricing the 3430, which has more features, lower than the 3411 so that customers will be willing to make the switch.

Results of the post-evaluation survey indicated that the operators preferred to use the Humboldt 5001P, Troxler 3430 and CPN MC-1DR over the more advanced gauges. These gauges were also much preferred over the Troxler 3401B, the current gauge, due to their direct readout capability.

Table 1

NUCLEAR GAUGE RETAIL PRICES

Model Evaluated	Manufacturer	Model	Retail Costs 8" Source Rod	Retail Costs 12" Source Rod
	CPN	MC-1	$3870	$4080
+	CPN	MC-1DR	$4200	$4400
+	CPN	MC-3	$5195	$5395
+	Humboldt	5001P	$4600	$4800
	Humboldt	5001C*	$4800±	
+	Troxler	3401	$3950	$4050
	Troxler	3411	$4550	$4650
+	Troxler	3430**	$4350±	
+	Troxler	3440	$5150	$5250
	Manufacturer	Model	Cost	
+	Seaman	C-75A	$4475 ($6000 as tested)***	
	Seaman	C 200	$6975 (Does not have direct transmission capability)	

*Not yet available. Will include printer interface; price is a preliminary estimate.

**Not yet available, prototype gauge was evaluated; price is a preliminary estimate. Should be available by Fall 1990.

***Gauge tested had direct transmission option and accessories

Figure 1

Nuclear Density Test Sites

Table 2

SOIL TEST SITE DATA

Site #	County	Route	General Location	Soil Type	Avg. Wet Density	Avg. % Moisture
4	Camden	7	Montreal	Clarksville	123.0	16.8
5	Lawrence	Y	Mount Vernon	Crawford	115.9	15.8
7	Pulaski	I-44 Spur	St. Roberts	Lebanon	126.9	10.9
8	Clay	1	Kansas City	Knox	122.3	20.0
10	Jasper	AA	Joplin	Eldon	112.9	10.2
11	Greene	60	Springfield	Crawford	116.1	26.1
16	Lafayette	13	Higginsville	Marshall	128.1	17.5
17	Cole	54	Jefferson City	Union	127.1	13.5
18	Laclede	5	Lebanon	Lebanon	125.4	17.0
19	Cole	HP Driving Course	Jefferson City	Memphis	120.7	17.0
23	Greene	I-44	Springfield	Crawford	112.2	16.3

BASE TEST SITE DATA

Site #	County	Route	General Location	Formation	Avg. Wet Density	Avg. % Moisture
6	Crawford	8	Steelville	Jeff City Dolo	138.2	5.6
12	St. Louis	I-270	St. Louis	St. Louis LS	126.6	5.5
14	St. Louis	I-44	Peerless Park	Burlington LS	131.9	3.2
17	Cole	54	Jefferson City	Jeff City Dolo	134.6	3.9
18	Laclede	5	Lebanon	Jeff City Dolo	132.9	4.9
20	Callaway	54	Jefferson City	Jeff City Dolo	142.2	5.1
21	Clay	210	Kansas City	Bethany Falls	137.7	3.5
22	Jackson	71	Kansas City	Bethany Falls	131.6	4.2
25	St. Louis	40	St. Louis	St. Louis LS	142.4	5.7

Table 3

DENSITY AND MOISTURE DATA FROM
VOLUMEASURE (BALLOON) METHOD

	Loc. 1		Loc. 2		Loc. 3		Loc. 4		
Site #	D	M	D	M	D	M	D	M	Comments
04 Soil	123.5	6.8	120.0	6.2	115.0	4.0	124.3	7.8	Rocky
05 Soil	115.0	12.0	113.6	13.7	100.2	13.3	115.7	10.5	Rocky
07 Soil	---	---	---	---	---	---	---	---	No tests
08 Soil	125.2	18.0	121.5	16.8	129.5	16.5	122.0	15.2	
10 Soil	---	---	---	---	---	---	---	---	No tests
11 Soil	---	---	---	---	---	---	---	---	No tests
16 Soil	125.6	18.7	120.9	14.1	129.2	17.3	124.5	17.0	Rocky
17 Soil	---	---	---	---	---	---	---	---	No tests
18 Soil	121.0	11.4	122.7	10.1	---	---	121.6	13.9	
19 Soil	114.8	16.3	118.6	14.1	118.9	14.8	115.9	15.8	
23 Soil	113.1	12.7	118.3	16.8	111.6	14.7	110.2	10.8	Rocky
06 Base	142.5	3.16	136.7	4.17	146.7	3.49	140.9	4.02	
12 Base	126.6	6.30	121.6	3.09	132.6	3.79	127.0	3.69	
14 Base	---	---	129.0	1.20	134.8	1.32	---	---	
17 Base	141.5	2.63	136.7	2.27	134.4	2.40	135.3	3.66	
18 Base	137.5	3.12	131.8	2.63	139.8	2.99	---	---	
20 Base	143.6	2.68	140.6	1.88	133.6	3.41	139.1	2.31	
21 Base	137.4	3.18	137.5	3.00	136.1	2.85	134.4	3.09	
22 Base	131.6	3.11	129.6	3.39	124.9	3.00	127.9	2.88	
25 Base	133.9	5.94	135.6	4.92	136.6	4.63	139.7	4.82	

Table 4

INDEX OF PRECISION
95% Probability
For Percent Moisture

Site Number	Seaman C75A AG/BS	Seaman C75A DT	Humboldt 5001P	CPN MC-1DR	CPN MC-3	Troxler 3440	Troxler 3401B	Troxler 3430
04 Soil	0.60	0.56	0.60	0.66	--	0.85	0.80	--
05 Soil	0.66	0.72	0.53	0.53	0.89	0.56	0.40	0.45
07 Soil	0.72	0.53	0.66	0.82	0.75	0.69	0.56	0.60
08 Soil	0.92	0.80	0.60	0.98	1.02	--	0.72	--
10 Soil	0.53	0.80	0.60	0.66	0.56	0.53	0.66	0.75
11 Soil	1.62	1.00	1.34	1.43	1.11	0.96	0.85	0.92
16 Soil	1.02	0.63	0.87	0.77	1.04	0.82	1.06	--
17 Soil	0.72	0.45	0.53	0.82	--	0.56	0.72	--
18 Soil	--	1.13	0.77	0.82	0.09	1.23	0.89	0.82
19 Soil	0.89	0.56	0.69	0.92	0.77	0.53	0.49	--
23 Soil	0.85	0.66	1.00	0.53	0.77	0.92	0.87	0.82
06 Base	0.53	0.35	0.28	0.53	0.49	0.53	0.40	0.40
12 Base	0.35	0.20	0.40	0.35	0.49	0.66	0.53	0.28
14 Base	0.20	0.40	0.49	0.28	0.60	0.49	0.40	--
17 Base	0.35	0.28	0.53	0.40	0.45	0.20	0.40	0.35
18 Base	0.35	0.75	0.40	0.40	0.45	0.35	0.35	0.20
20 Base	0.28	0.40	0.40	0.28	0.28	0.45	0.45	--
21 Base	0.49	0.49	0.40	0.40	0.28	0.28	0.49	--
22 Base	0.20	0.28	0.28	0.35	0.40	0.28	0.28	--
25 Base	0.35	0.20	0.35	0.20	0.35	0.40	0.40	0.35
All Soils	0.89	0.75	0.77	0.85	0.28	0.80	0.77	0.75
All Bases	0.35	0.40	0.40	0.35	0.45	0.45	0.40	0.28
All Materials	0.69	0.60	0.63	0.66	0.69	0.66	0.63	0.60

Table 5

INDEX OF PRECISION
95% Probability
For Wet Density

Site Number	Seaman C75A AG/BS	Seaman C75A DT	Humboldt 5001P	CPN MC-1-DR	CPN MC-3	Troxler 3440	Troxler 3401B	Troxler 3430
04 Soil	1.06	0.75	0.56	0.85		0.40	0.40	--
05 Soil	0.89	0.77	0.35	0.28	0.45	0.40	0.28	0.35
07 Soil	0.89	0.72	0.60	0.56	0.53	0.53	0.52	0.28
08 Soil	0.82	0.63	0.49	0.28	0.28	--	0.49	--
10 Soil	0.82	0.66	0.40	0.53	0.40	0.53	0.45	0.40
11 Soil	0.80	0.72	0.28	0.40	0.49	0.45	0.69	0.35
16 Soil	0.94	0.80	0.40	0.40	1.30	0.45	0.45	--
17 Soil	5.21	1.31	0.35	0.40	--	0.40	0.35	--
18 Soil	--	0.98	0.45	0.45	0.35	0.35	0.49	0.45
19 Soil	10.15	0.53	0.53	0.35	0.40	0.53	0.35	--
23 Soil	4.53	0.35	4.67	0.35	0.56	0.40	0.35	0.35
06 Base	1.44	0.35	0.60	0.45	0.77	0.80	0.53	0.56
12 Base	0.96	0.35	0.45	0.28	0.49	1.20	0.56	0.45
14 Base	0.77	0.49	0.92	2.76	0.66	0.66	0.49	--
17 Base	0.96	0.53	0.40	0.53	0.49	0.53	0.72	0.63
18 Base	0.98	0.92	0.56	0.20	0.49	0.40	0.66	0.80
20 Base	0.87	0.53	0.35	0.53	0.53	0.66	0.75	--
21 Base	1.23	0.40	0.45	0.40	0.35	0.63	0.40	--
22 Base	1.55	0.87	0.49	0.45	0.45	0.35	0.28	--
25 Base	0.80	0.40	0.53	0.56	0.40	0.56	0.53	0.72
All Soils	3.97	0.80	1.50	0.45	0.60	0.45	0.49	0.40
All Bases	1.11	0.56	0.56	1.02	0.53	0.66	0.56	0.66
All Materials	2.97	0.72	1.18	0.75	0.63	0.56	0.53	0.49

Table 6

STANDARD DEVIATION
FROM AVERAGE READINGS PLUS
VOLUME MEASURE DENSITY

Site Number	Seaman C75A AG/BS	Seaman C75A DT	Humboldt 5001P	CPN MC-1-DR	CPN MC-3	Troxler 3440	Troxler 3401B	Troxler 3430
04 Soil	10.35	5.38	2.74	4.07	--	4.32	5.90	--
05 Soil	17.06	7.06	3.85	3.29	3.70	5.40	7.46	4.74
07 Soil	19.22	2.71	3.28	2.80	3.44	3.38	5.41	2.30
08 Soil	8.71	7.10	4.73	4.21	3.61	--	6.31	--
10 Soil	17.53	4.84	2.80	2.80	2.81	3.48	5.48	4.46
11 Soil	9.80	3.92	2.38	2.20	2.78	1.44	4.23	3.15
16 Soil	4.37	2.38	1.31	1.47	1.23	1.27	3.54	--
17 Soil	15.24	4.58	4.40	4.09	--	4.31	6.34	--
18 Soil	--	4.54	1.08	1.17	1.49	1.29	4.20	4.01
19 Soil	11.48	2.75	3.23	2.32	4.26	2.54	5.76	--
23 Soil	19.19	13.92	6.34	5.75	6.04	4.95	6.83	3.56
Avg. Deviation Soil	13.30	5.38	3.28	3.11	3.26	3.24	5.59	3.70
06 Base	15.86	7.08	3.36	2.12	3.75	4.53	6.94	3.25
12 Base	8.17	4.92	1.92	1.44	1.10	5.35	4.34	2.51
14 Base	1.79	2.54	3.59	1.48	1.95	2.37	3.09	--
17 Base	18.03	4.96	1.86	1.27	0.81	1.14	4.82	3.10
18 Base	21.06	4.94	4.09	3.39	3.83	4.10	7.19	4.76
20 Base	14.40	1.24	2.40	3.56	3.34	3.29	6.29	--
21 Base	2.62	3.35	1.33	1.22	2.63	2.55	4.06	--
22 Base	4.46	4.45	1.26	1.16	1.31	1.42	3.80	--
25 Base	7.08	4.99	0.74	1.55	2.90	1.93	4.63	2.45
Avg. Deviation Base	10.38	4.27	2.28	1.91	2.40	1.96	5.02	3.21
Avg. Gauge Deviation	11.92	4.88	2.83	2.57	2.83	3.11	5.33	3.48

Table 7

STANDARD DEVIATION
FROM AVERAGE OF DIRECT
TRANSMISSION GAUGES

Site Number	Seaman C75A AG/BS	Seaman C75A DT	Humboldt 5001P	CPN MC-1-DR	CPN MC-3	Troxler 3440	Troxler 3401B	Troxler 3430
04 Soil	14.02	8.75	1.04	0.44	--	0.68	2.28	--
05 Soil	21.09	10.97	0.37	0.31	0.89	1.49	3.46	0.67
07 Soil	22.13	4.23	0.46	1.32	1.35	0.76	2.94	0.72
08 Soil	11.07	8.42	4.81	2.74	2.14	--	5.17	--
10 Soil	20.47	7.25	1.35	1.56	1.32	0.98	2.51	1.91
11 Soil	11.30	5.07	1.57	0.91	1.78	0.78	2.78	3.30
16 Soil	5.44	3.54	0.66	0.38	0.22	0.43	2.47	--
17 Soil	19.39	8.39	0.84	1.15	--	0.33	2.18	--
18 Soil	--	5.06	1.24	0.88	1.27	1.10	3.90	3.92
19 Soil	14.22	5.27	1.23	0.72	1.74	2.11	3.22	--
23 Soil	24.12	18.70	2.11	1.18	1.55	1.21	1.92	3.85
Avg. Deviation Soil	16.32	7.79	1.42	1.14	1.36	0.99	2.98	2.40
06 Base	18.29	9.41	1.14	1.25	4.18	2.66	4.60	1.55
12 Base	8.10	5.33	1.96	1.29	0.77	5.18	4.58	2.55
14 Base	1.81	3.01	3.36	1.90	2.06	1.94	3.30	--
17 Base	19.31	4.19	0.94	1.30	0.99	0.93	3.55	1.80
18 Base	23.72	7.84	2.13	1.65	3.98	2.65	4.66	2.76
20 Base	17.40	4.23	1.71	0.89	0.51	0.43	3.53	--
21 Base	2.63	4.16	1.33	0.86	2.48	2.26	3.81	--
22 Base	4.84	4.63	1.41	0.65	1.09	1.17	3.98	--
25 Base	7.94	4.64	1.31	0.70	2.74	1.41	3.73	1.58
Avg. Deviation Base	11.56	5.27	1.70	1.16	2.09	2.07	3.97	2.05
Avg. Gauge Deviation	14.07	6.65	1.55	1.15	1.72	1.50	3.43	2.24

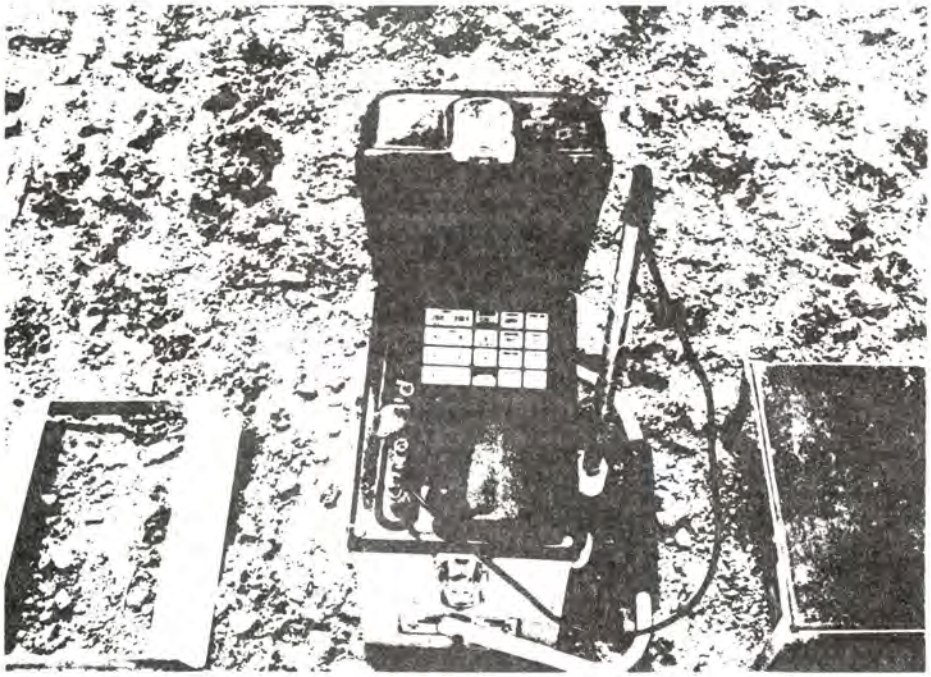
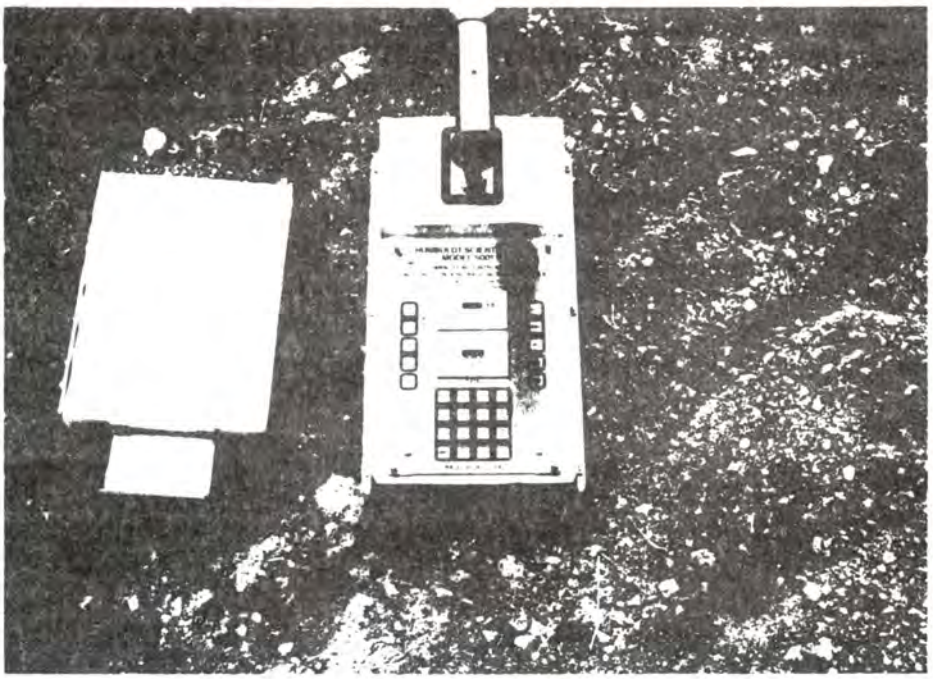


Figure 2

Seaman
C-75-A



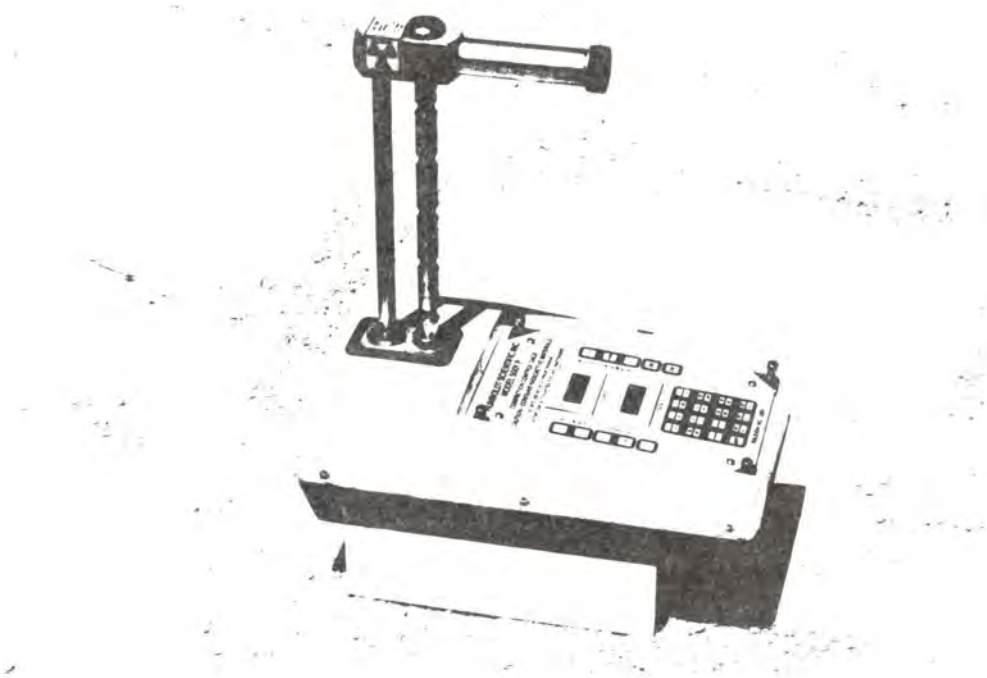
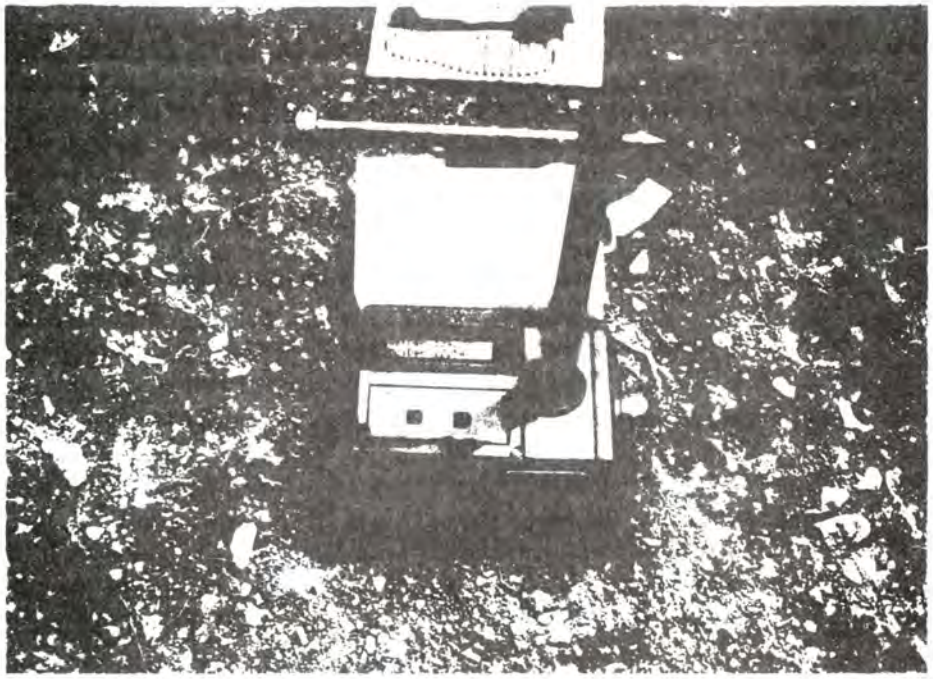


Figure 3

Humboldt
5001P



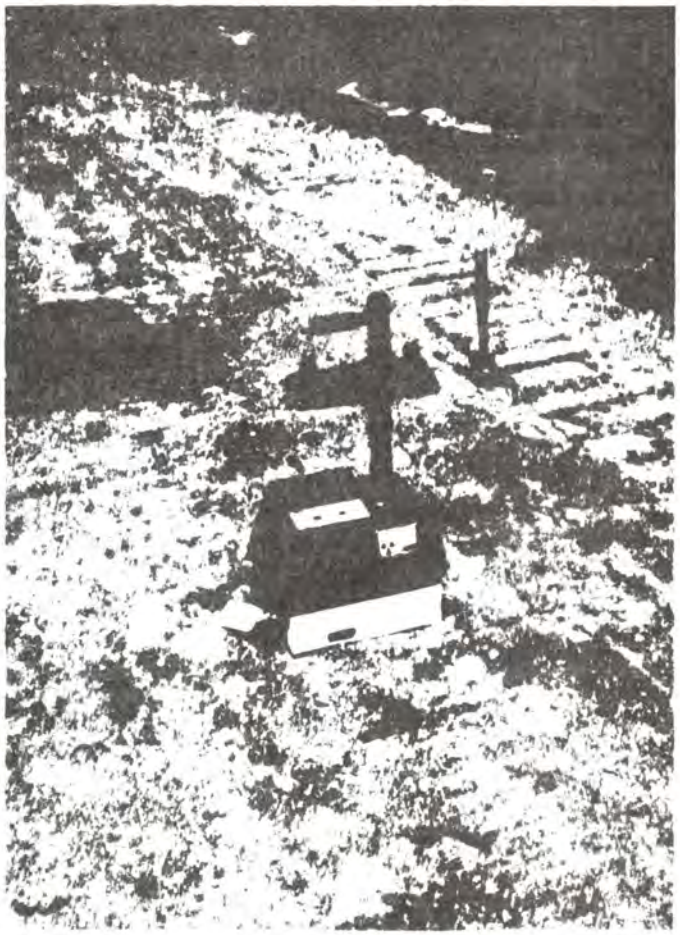


Figure 4

CPN
MC-1DR

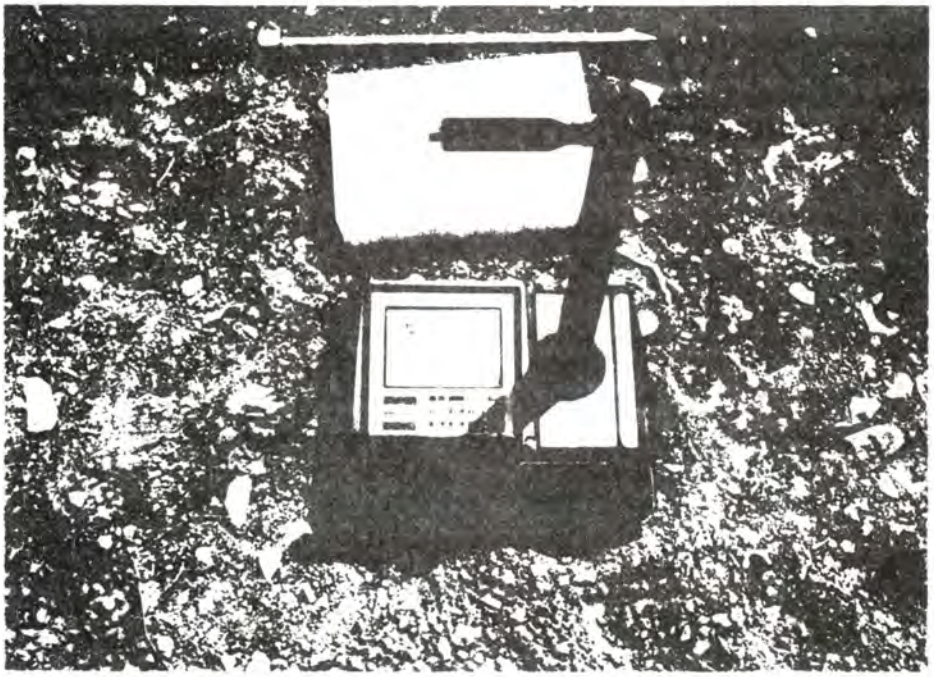


Figure 5

CPN
MC-3

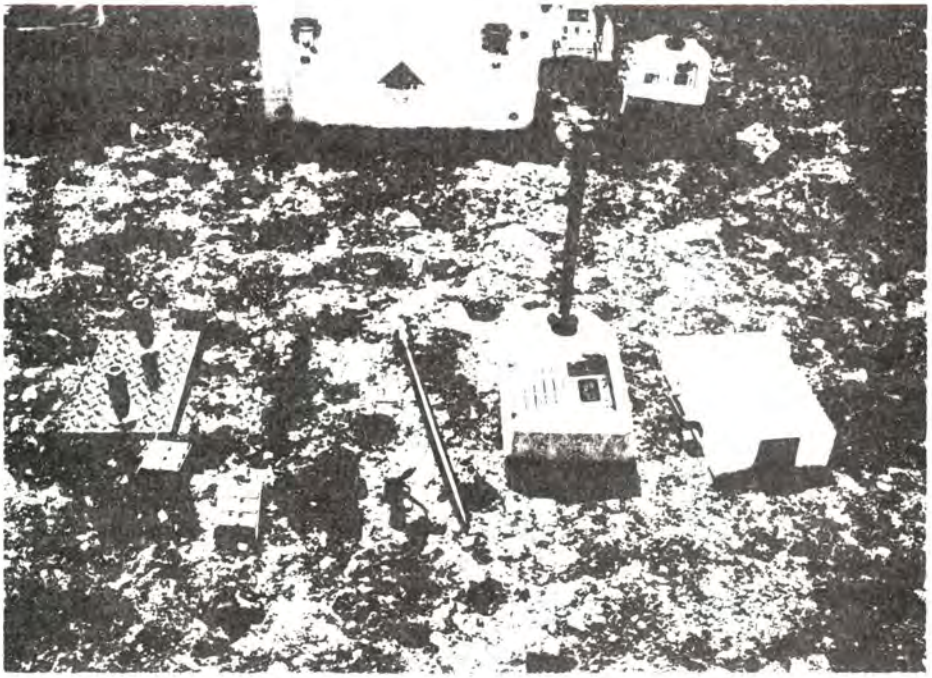
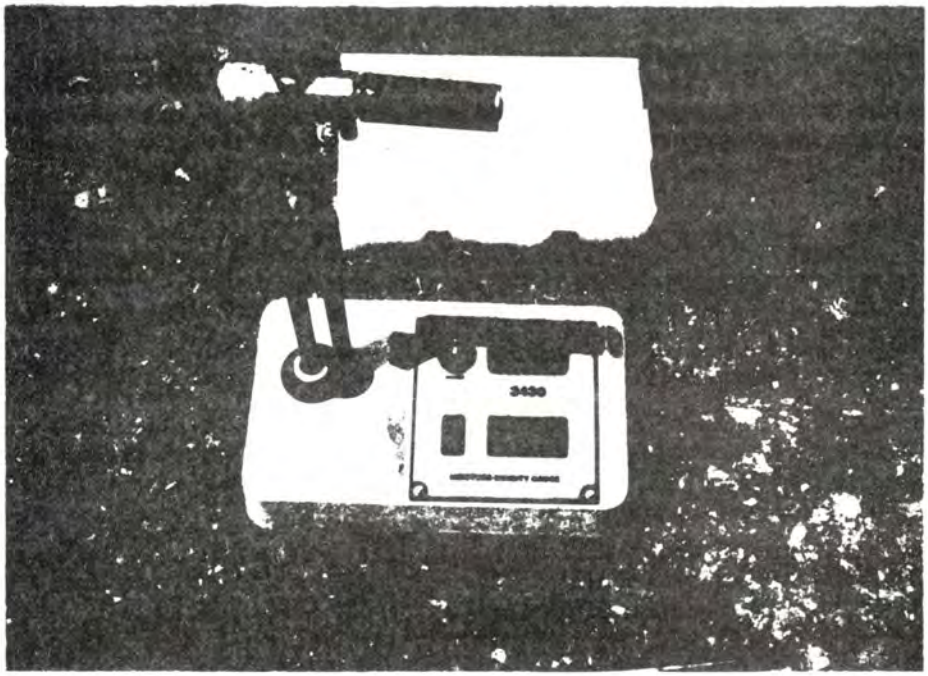


Figure 6

Troxler
3440



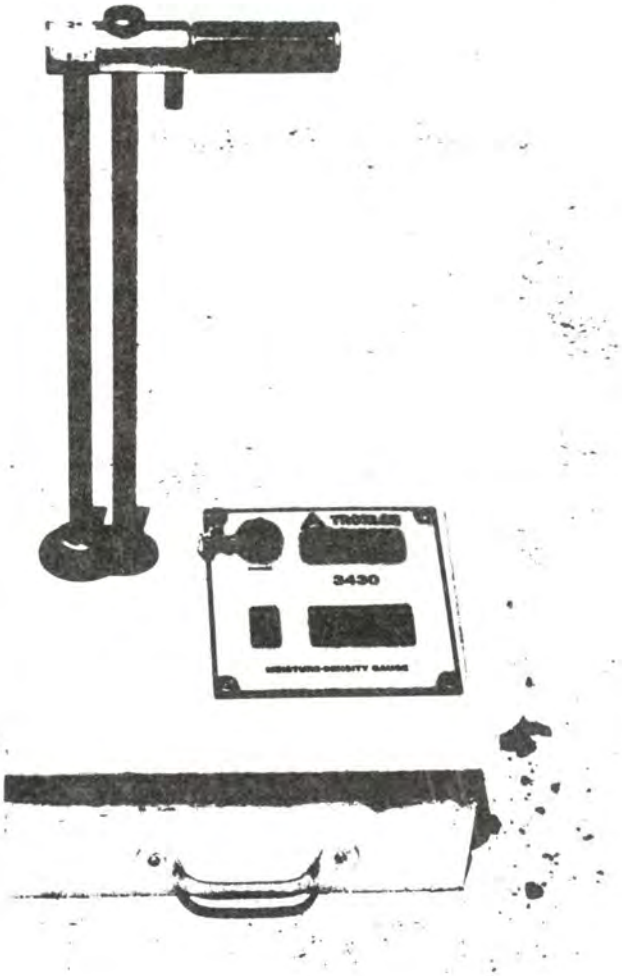


Figure 7

Troxler
3430

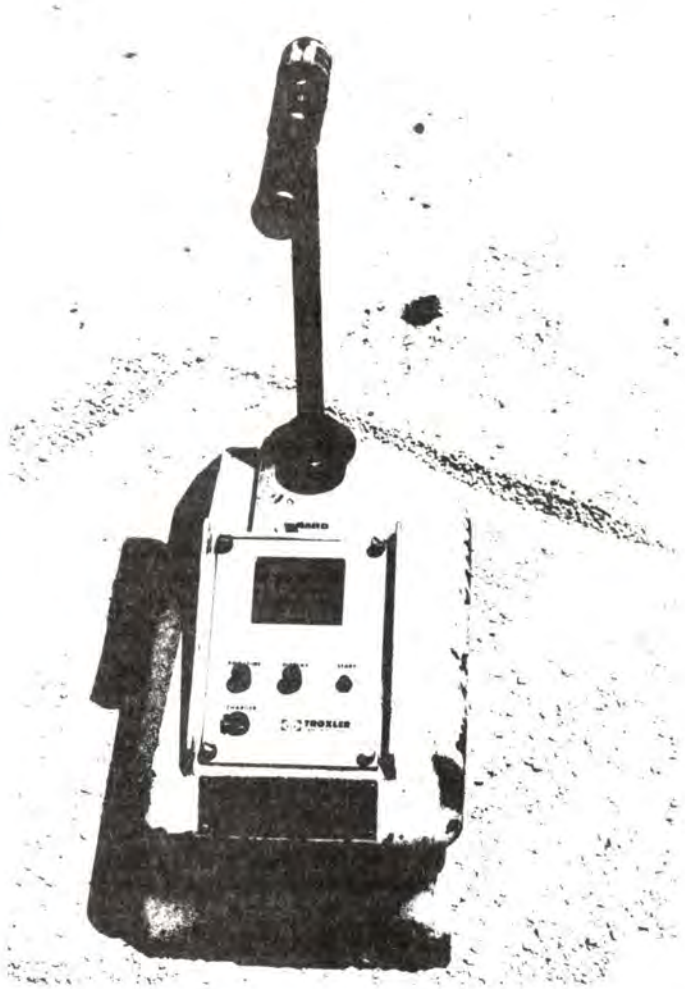


Figure 8

Troxler
3401B