THE MICHIGAN COMBINATION DENSITY-MOISTURE GAGE FOR SOILS

B. W. Pocock, L. W. Smith, W. H. Schwartje, and R. E. Hanna

Research Laboratory Division
Office of Testing and Research
Report No. 311
Research Projects 55 H-4, 56 H-5

Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, March 1959

THE MICHIGAN COMBINATION DENSITY-MOISTURE GAGE FOR SOILS

Introduction

The Michigan State Highway Department's combination density-moisture gage is a non-destructive 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 embedded in a lead block inside the gage. This capsule contains a tiny amount of radium-beryllium, which furnishes the radiation for the interactions with the soil. The radiation is of two kinds, gamma rays and fast neutrons. Since radium has a half-life of 1620 years, the radiation is relatively constant.

The gamma rays on penetrating the soil undergo scattering as a result of collisions with electrons contained in the soil atoms. The more soil atoms there are present, the more scattering takes place, and this scattering occurs in all directions. Simultaneously with the scattering, however, the gamma rays are absorbed in the soil, and the greater the density, the greater is this absorption. The scattered gamma rays which are not absorbed are detected by two gamma-ray counter tubes in parallel circuit in the gage. The number detected per minute varies inversely with the soil density.

The fast neutrons emitted from the capsule undergo elastic collisions with the nuclei of hydrogen atoms contained in the water molecules of soil moisture, and are likewise scattered in all directions. Each typical collision greatly reduces the velocity of the neutrons, so that after several collisions they are slowed to "thermal" velocities (about 7218 ft/sec). The number slowed by this process varies directly as the number of hydrogen atoms present, hence as the moisture content of the soil. The "thermal" or slow neutrons are detected by two slow neutron counter tubes in parallel circuit in the gage, which are insensitive to anything else. The number detected per minute varies directly with the moisture content.

Historical Development

The Michigan combination gage is the product of three years' research conducted in the Research Laboratory Division subsequent to investigations reported in the Michigan State Highway Department Office of Testing and Research Report No. 261, July, 1956, "An Analysis of Certain Mathematical Assumptions Underlying the Design and Operation of Gamma-Ray Surface Density Gages." A condensed version of this report appeared in the 1958 Proceedings of the American Society for Testing Materials.

Preliminary work with individual pilot models in the laboratory and in the field indicated the soundness of the physical principles involved in measuring soil density and moisture by the nuclear method. Other workers reported favorable results and published designs for density gages and moisture gages which they considered satisfactory. At least one firm began making nuclear density gages and moisture gages available commercially.

All of the nuclear gages reported or available commercially were of the individual type; that is, they either detected density or moisture but not both. The moisture gages usually used radium-beryllium as a source of neutrons, but the gamma rays from this source were totally neglected as undesirable. The density gages used either cesium 137 or cobalt 60 as a source of gamma rays.

The Michigan State Highway Department recognized the desirability of having a single nuclear gage which could be used for both density and moisture determinations, and research was undertaken to establish the feasibility of using the gamma radiation from the radium of the radium-beryllium source for accurate detection of soil density.

It was found that this gamma radiation could indeed be employed for accurate density determinations provided the gage were properly designed. Proper design included the introduction of gamma-ray counter tubes separated from the radioactive source by a lead absorber of optimum thickness, as described in Report No. 261; a built-in electronic cathode follower circuit; placement of slow neutron counter tubes with strict relation to their point of maximum sensitivity; and a built-in electronic preamplifier circuit.

Design Features

Illustrations, design features, and details of construction of the Michigan gage are shown in Figures 1 through 4. An operating manual was prepared for field density crews who might have to be trained to use the gage and was published as Michigan State Highway Department Office of Testing and Research Report No. 308, "Operating Manual for Soil Density and Moisture Measurements by Nuclear Methods," March, 1959.

Method of Operation

In use, the gage is placed on the soil and is connected by a cable to a battery-operated portable scaler (electronic counter). A toggle switch on the scaler permits determination of the count rate from either the gamma-ray tubes or the slow neutron tubes in the gage. The count rate from the gamma-ray tubes (toggle switch at "Density" on the scaler) is determined either with a stop watch or with the timer built into the scaler, and is used to read the density of the soil on a density calibration curve directly in units of pounds per cubic foot, wet basis. The count rate from the slow neutron tubes (toggle switch at "Moisture" on the scaler), determined the same way, is used to read the moisture content of the soil on a moisture calibration curve directly in units of percent moisture by weight, dry basis.

Practical field experience on construction projects covering over 500 determinations of both density and moisture indicates that a one-minute count is sufficient for determination of either density or moisture. This means that the operator may have both results in a little over two minutes, well within the limit of accuracy demanded for routine construction practice.

Use of the Standard

The standard used with the gage is a wooden box filled with paraffin and capped with quarter-inch Masonite for durability. Dimensions are 7" high, 15" wide, and 20" long. Weight is 60.5 lb. In use it is placed on an empty wood box with the Masonite side 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 to previously selected standard rates and all field count rates are adjusted by the difference for the next four hours in practice. The reason that paraffin is used as a moisture as well as a density standard lies in the fact that paraffin contains a copious supply of hydrogen atoms.

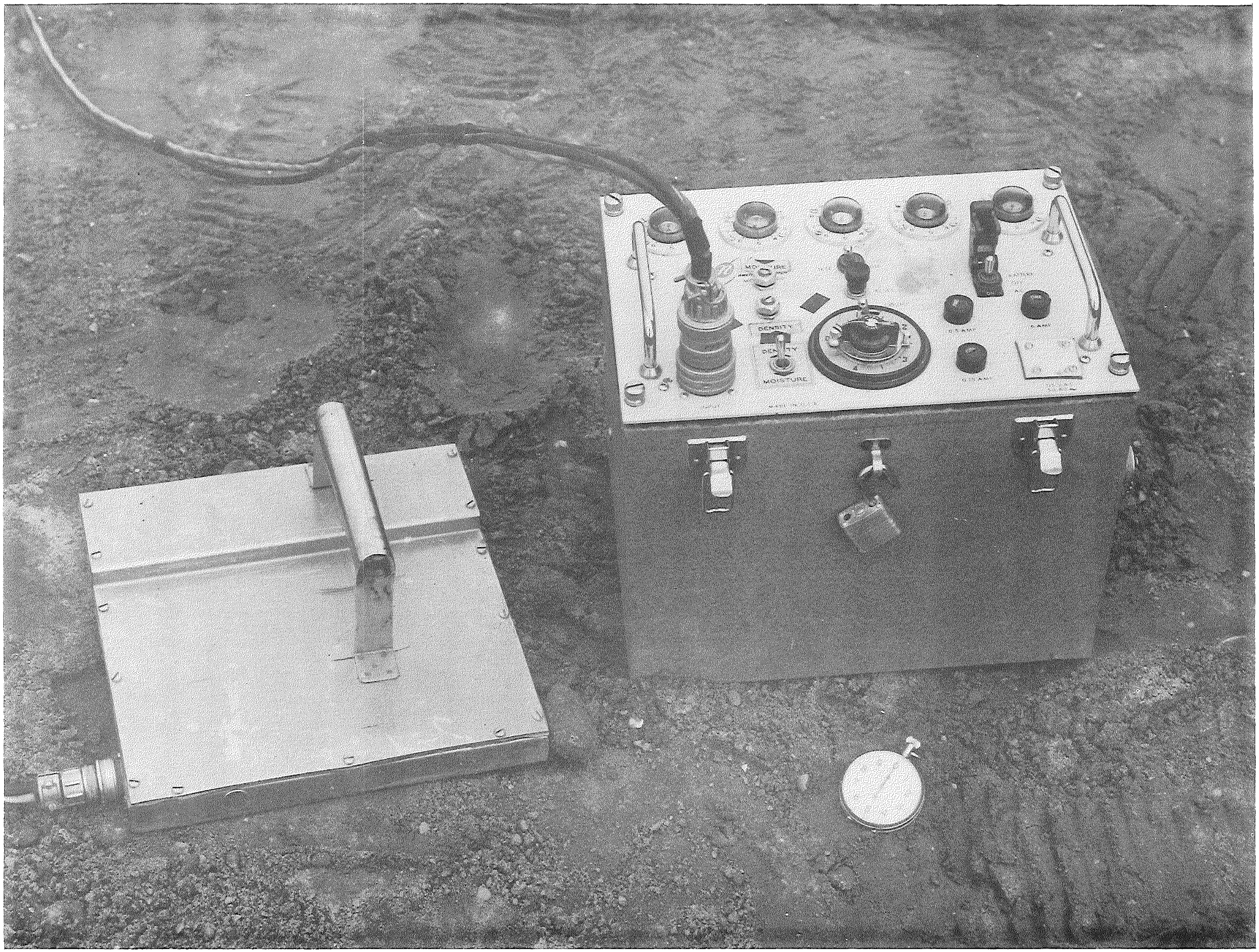
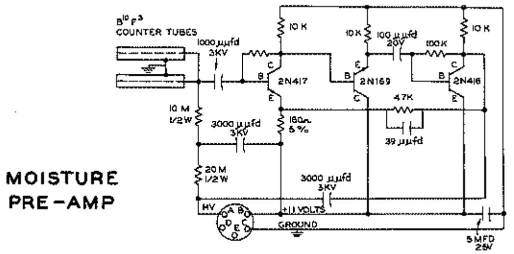


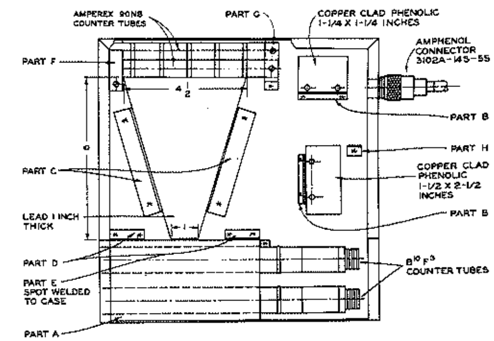
Figure 1. Michigan Combination Density-Moisture Gage connected to companion portable scaler.

Figure 2. Michigan Gage in use. Operators: Jack Lund and Larry Miller

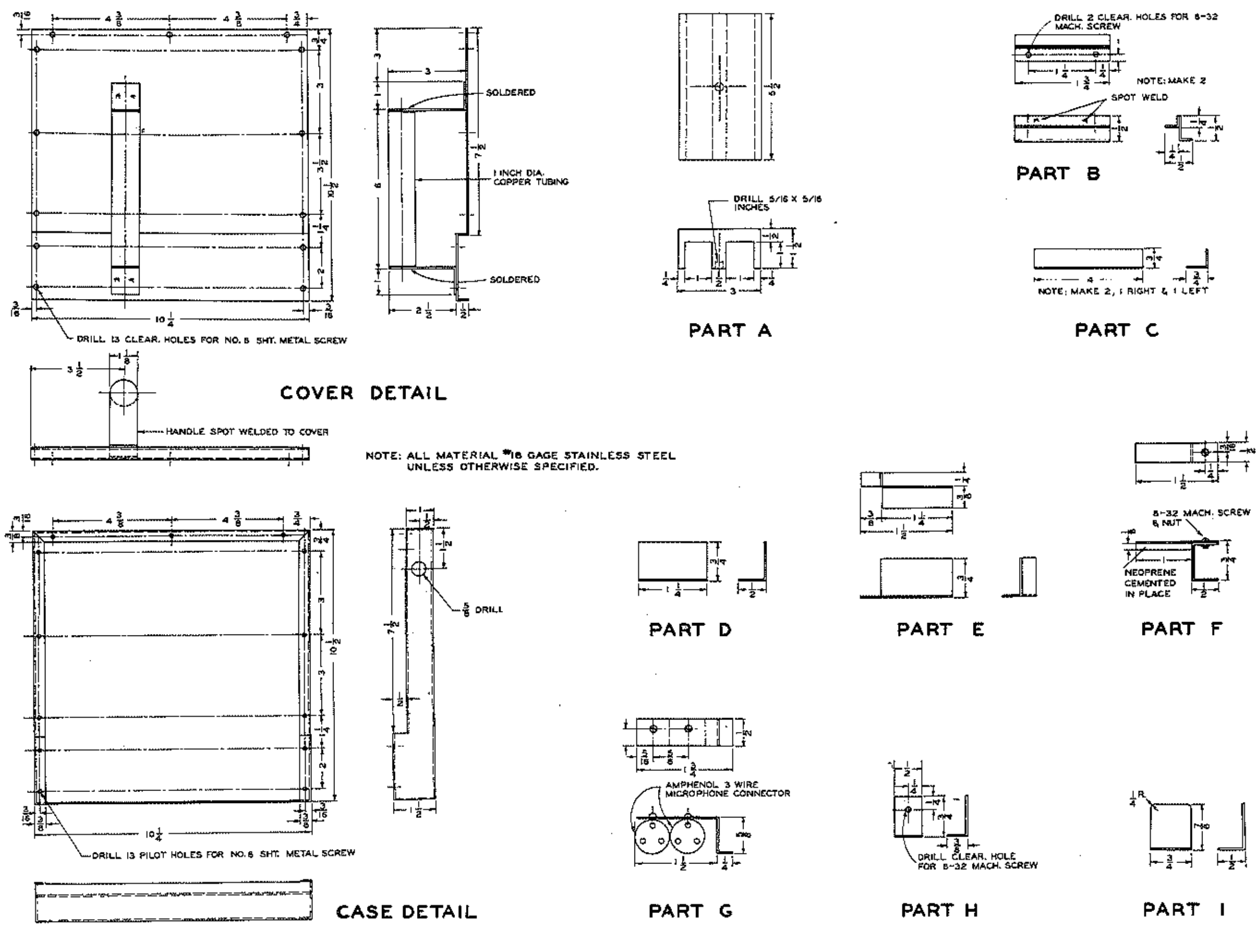
Figure 3. Method of running standard density and moisture count rates with the Michigan Gage.
Operator: Jack Lund.



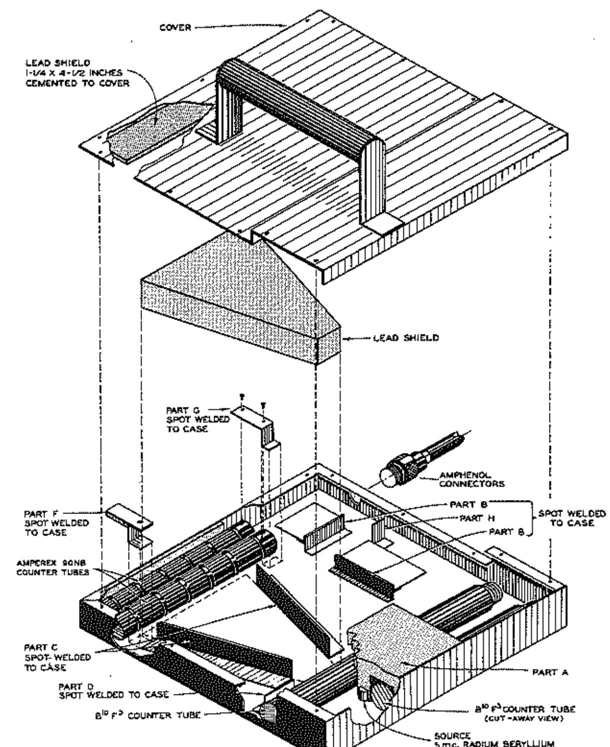
Electrical Schematics for the Combination Gage.



Plan View of the
Combination Moisture and Density Gage.



Detail Drawings of the Combination Gage.



Exploded View Assembly drawing
of the Combination Gage.

Figure 4. Engineering Drawings of the Combination Gage.

It has been found that two standard determinations are usually enough for a normal working day, one in the early morning and one in the early afternoon. Variations in the density standard count rates are due to changes in the local background radiation caused by different amounts of atmospheric radon and thoron; variations in the moisture standard count rate reflect changes in absolute atmospheric humidity. Although no temperature dependency of any part of the gage or scaler has been detected within the zero to 90 degrees F. range experienced so far, any such dependency would certainly be minute and should be compensated for by this method of using the standard.

Calibration Curves

Figures 5 and 6 show the calibration curves for density and moisture. Count rates for density are adjusted according to the count rate on the standard, referring to a standard count rate of 13,000 counts per minute. Count rates for moisture are similarly referred to a standard count rate of 2,900 counts per minute, and are adjusted accordingly.

The first 100 density determinations obtained with the gage on a construction project for which determinations were also made with the balloon apparatus are plotted in Figure 7, which shows nuclear results plotted against conventional results. The correlation coefficient, r, for this graph is 0.941.

The first 100 moisture determinations obtained with the gage on the same project, for which determinations were also made by driving the water off over a hot plate, are plotted in Figure 8, showing nuclear results against conventional results. The correlation coefficient, r, is 0.979.

Soils on which these determinations were made included loamy sand backfill, both with and without the presence of large stones; clay and sand mixtures; sand; sand and gravel mixtures; sand, gravel, clay, and silt mixtures; stony material; and clay.

Comparison with Moisture on a Volume Basis

Others who have reported results of moisture determinations by the neutron method have invariably established their calibration curves by plotting count rates against known weights of water per cubic foot of soil. Conversion from pounds per cubic foot to percent by weight is then made

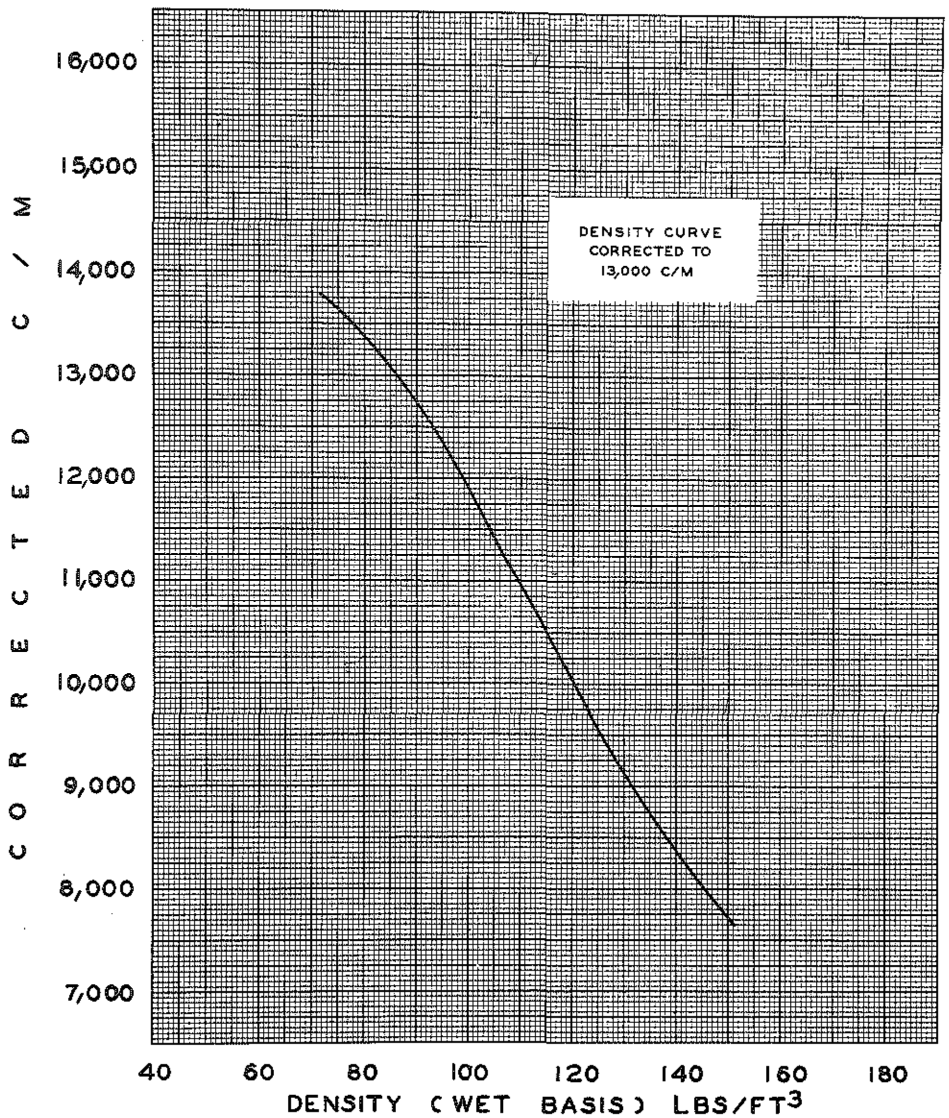


Figure 5. Calibration Curve for Density
M. S. H. D. Combination Nuclear Density-Moisture Gage.

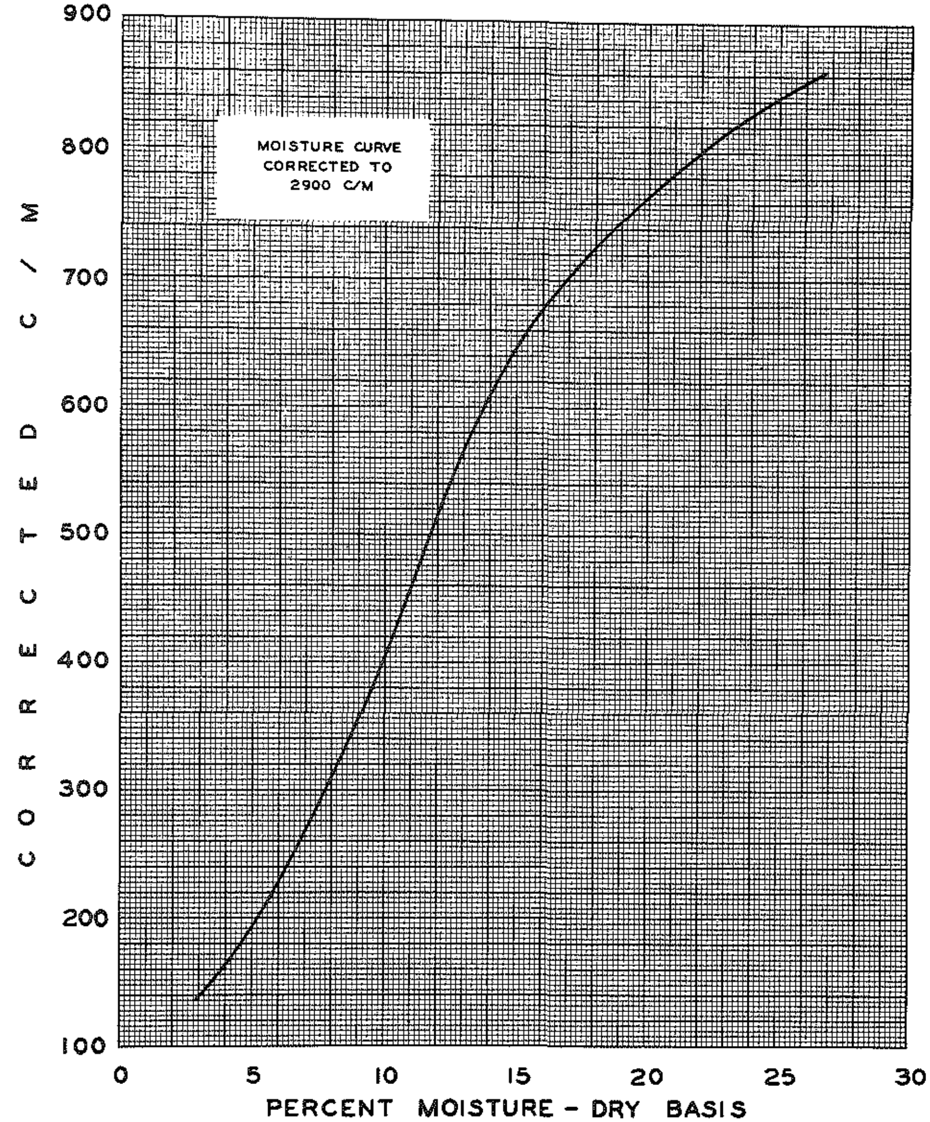


Figure 6. Calibration Curve for Moisture
M. S. H. D. Combination Nuclear Density-Moisture Gage.

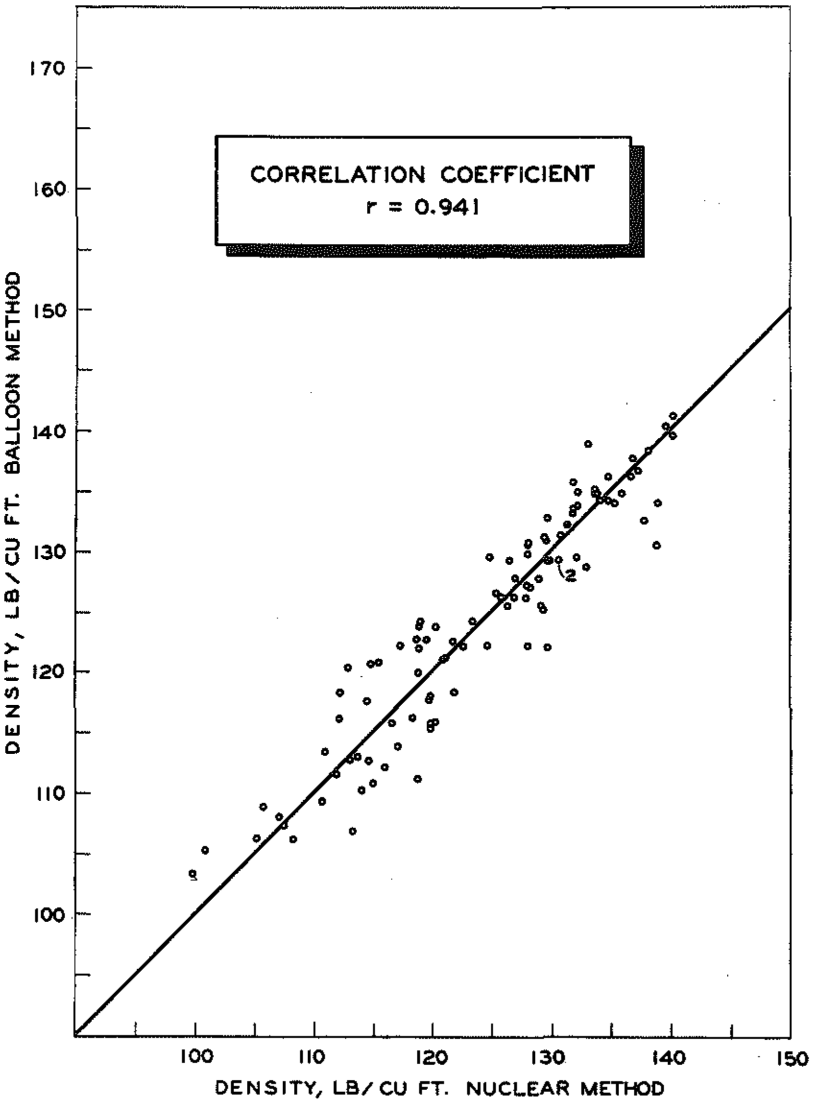


Figure 7. Conventional vs Nuclear Density.

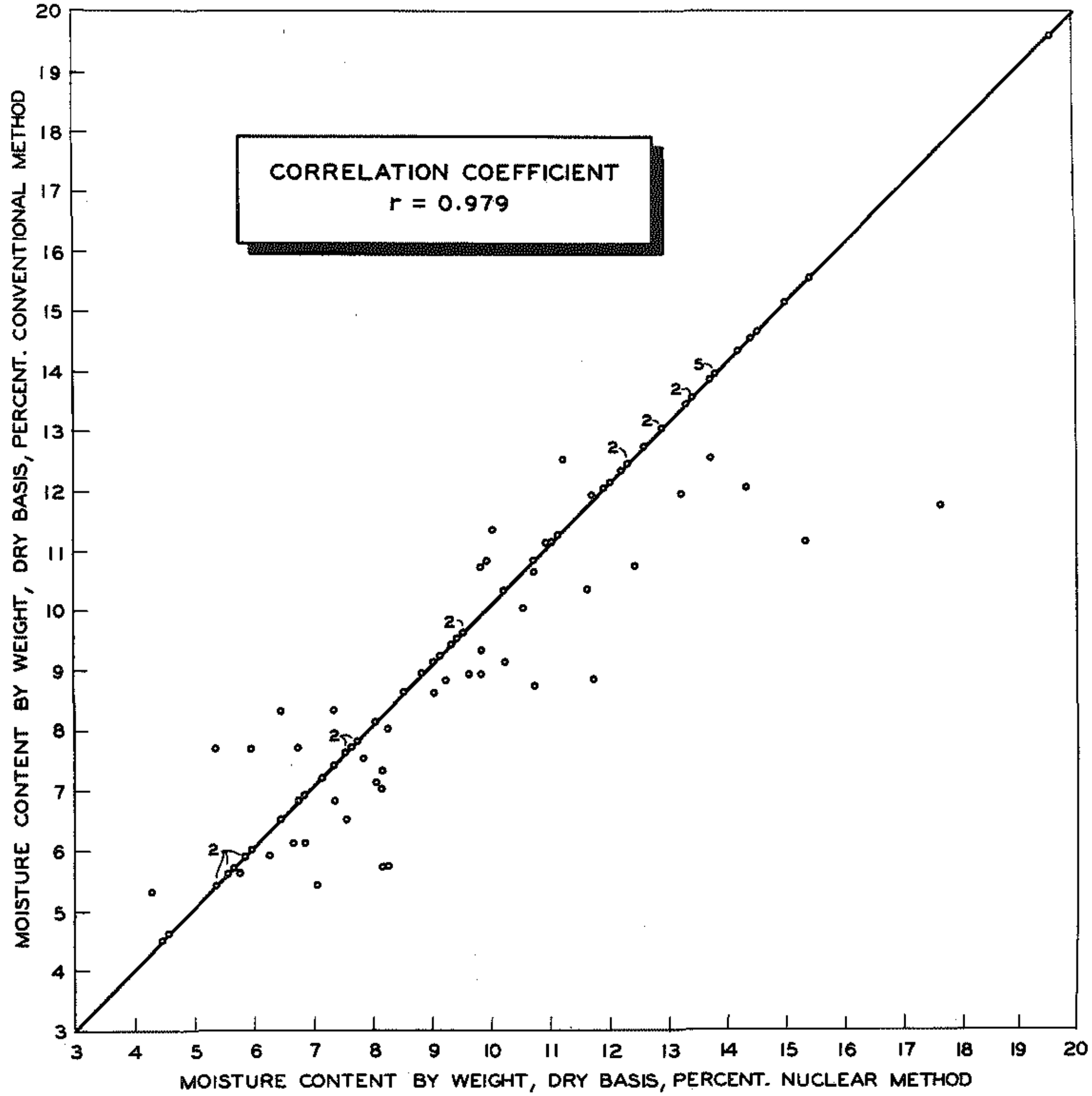


Figure 8. Conventional vs Nuclear Moisture.

by dividing the result by the unit weight of the soil. This method, of course, has two disadvantages: the extra computation plus the necessity of knowing the density.

The Michigan calibration curve was established by plotting count rates against known percentages of moisture by weight, dry basis. Results are thus obtained directly in units desired, and it is not necessary to know the density in order to determine the moisture content. The only rational explanation of this seeming paradox is that the volume of the sphere of influence of the neutron or moisture portion of the gage must vary inversely with the density.

A comparison of the accuracy of both methods was made by multiplying the moisture results obtained by conventional means for the 100 moisture points, by density results obtained with the balloon equipment for the same samples. This converted the conventional moisture results into units of pounds per cubic foot. These results were then plotted against the count rates obtained with the nuclear gage, and the resulting calibration curve is shown in Figure 9. This curve is a straight line, as reported by other workers. Moisture contents on the volume basis were read from the curve for each of the 100 points, and these were divided by the conventionally-determined densities, thus converting back to engineering units. These results were plotted against conventional results as shown in Figure 10. The correlation coefficient, r, for this comparison is 0.945. Our conclusion based on the evidence to date is that the Michigan calibration curve for moisture is at least as accurate as calibration curves established on a volume basis, with the advantages that results are obtained in immediately useful units and that it is not necessary to know the density in order to determine the moisture content.

Health and Safety

With reference to health and safety aspects, it is felt that the design of the Michigan gage effectively precludes any hazard to personnel operating the gage according to instructions. Practical common-sense safety rules are included in the operator training program.

As a legal precaution, arrangements should be made, and are made in Michigan, for all gage operators to have semiannual health examinations including blood counts and urinalyses, and to wear film badges sensitive to ionizing radiation including neutrons when working with the gage. Several commercial firms such as Tracerlab of Boston, Massachusetts,

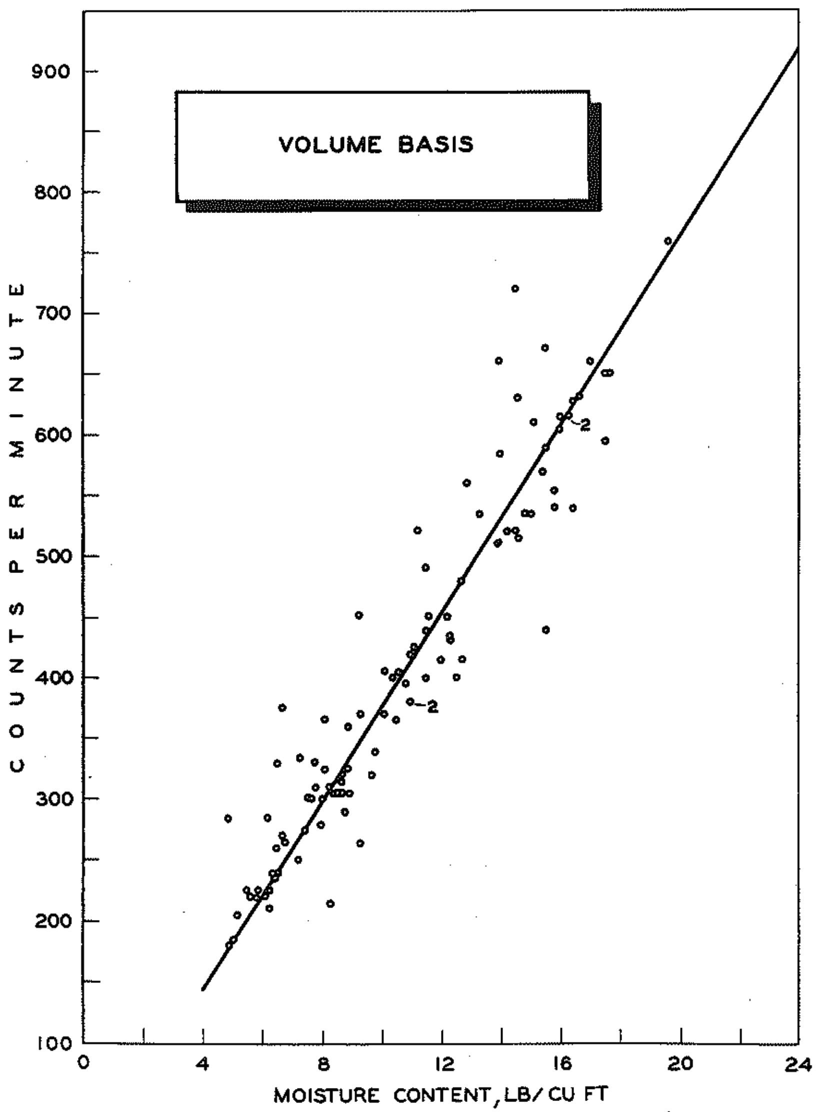


Figure 9. Calibration Curve for Moisture. Volume Basis

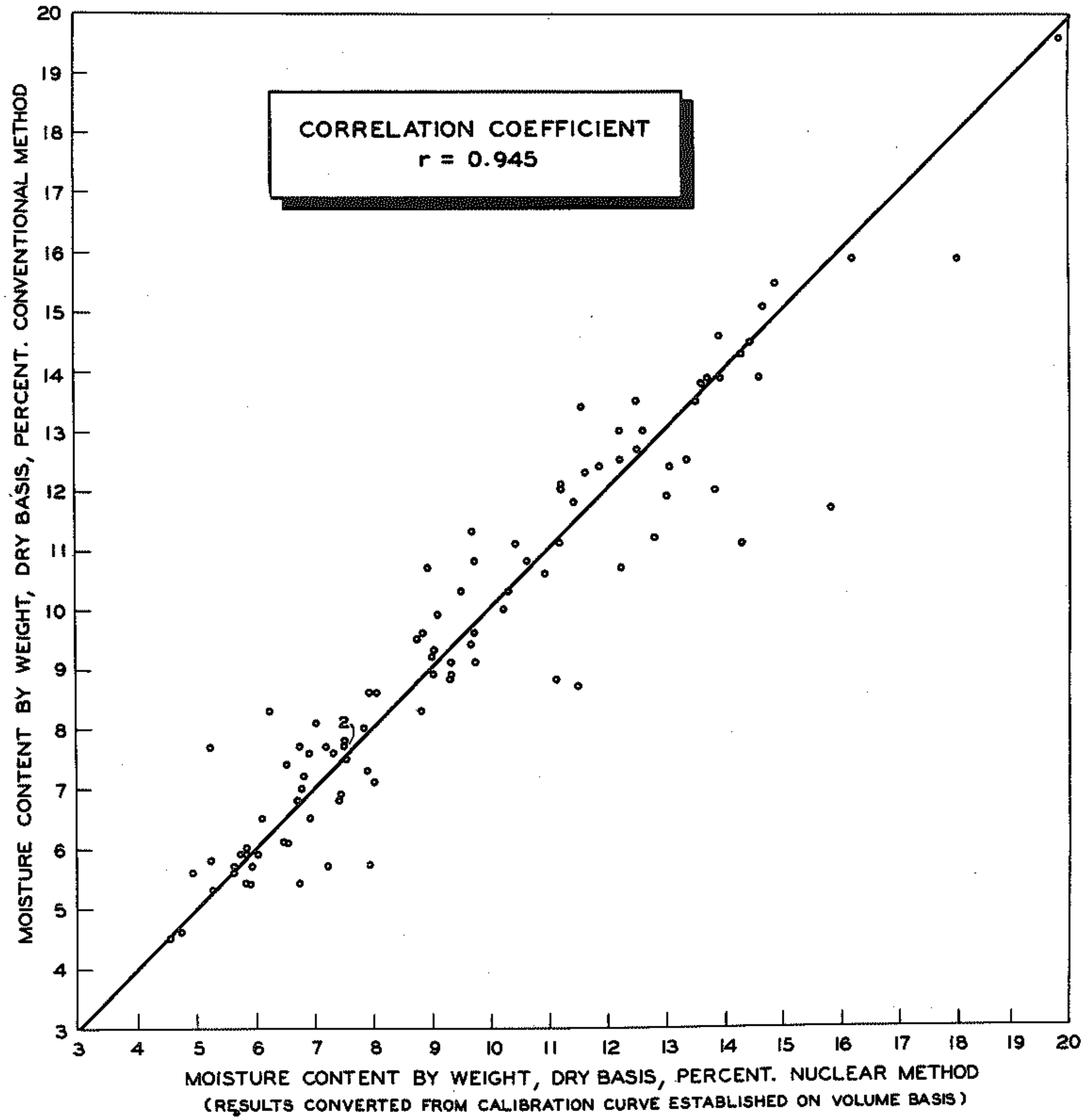


Figure 10. Conventional vs Nuclear Moisture. Nuclear results converted from calibration curve established on volume basis.

supply satisfactory film badge service. A typical film badge is shown in Figure 11. All records should be maintained for the life of the individual.

Regulatory Agencies

The United States Atomic Energy Commission possesses no regulatory power over naturally-occuring 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-weeks 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.

Economic Aspects

Individual nuclear density gages are available commercially for $1285. The companion moisture gages are priced at $1750. The Michigan combination gage costs approximately $600 for all parts including the standard. It is estimated that construction costs are in the neighborhood of $400 for labor, on a unit basis. The portable scaler used with all these instruments, also available commercially, sells for $1345.

A conventional field density control unit in Michigan consists of a vehicle, two men, and all the usual equipment for conducting balloon method density tests and hot-plate moisture tests in addition to sand cone and Proctor determinations. It usually averages out that conventional routine density and moisture control tests require about 30 minutes. Preliminary experience based on over 500 nuclear determinations shows that over ten density and moisture determinations can be obtained during the time it would take to obtain one determination of density and moisture by conventional methods.

Figure 11. Typical film badge carried by operators using the Michigan Gage.

Although this potential has occasionally been realized, it is the exception rather than the rule, due to time lost in moving from place to place on the grade. It is felt that much of this lost time can be eliminated by equipping the two-man crew with a panel truck, thus making it unnecessary to disconnect the scaler from the gage when changing locations, and at the same time furnishing plenty of room for such accessory equipment as that used for determinations of percent of maximum compression.

One complete nuclear device including the scaler costs about half as much as ten conventional sets of density-moisture apparatus, yet the results are roughly comparable. Ten conventional setups require 10 men and 10 vehicles. At present one nuclear device requires two men, one of whom determines percentages of maximum compaction and records data, and one vehicle.

Operator Training

No outstanding educational background or unusual talents, other than normal intelligence and a willingness to learn, are required in order to operate the Michigan gage, although a three-day training program is recommended for new operators. During this period the trainee studies the operating manual and uses the gage under close supervision. He is given some background in elementary nuclear concepts and is made to feel that he is "getting in on the ground floor" in a new area of engineering technology. The response has invariably been excellent.