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Use of the supplied hammer and drill rod requires driving the rod into compacted soil or other hard materials and may cause damage to the user due to flying particles from the hammer, drill rod or the materials under test. Safety glasses must be utilized for this procedure.

See Section 9 for Equipment Warranty.

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1 GENERAL AND SPECIFICATIONS

1.1 Introduction

This Density/Moisture Gauge, the HS-5001EZ-2, is specifically designed to measure the moisture content and density of construction materials.

The microprocessor-based units automatically compute these parameters and makes corrections to the measurements.

It uses the attenuation of gamma radiation due to Compton scattering and photoelectric absorption. It is directly related to the electron density of materials as an indication of the mass density of specific materials having a chemical composition approximating the crust of the earth.

The standard factory supplied density calibration is based on a material consisting of 50% limestone and 50% granite as being very close to the average material encountered in engineering construction. This calibration may be altered by the user to best fit other materials, which may have a chemical composition vastly different from the supplied calibration.

The measurement of moisture content is based on the thermalization (slowing down) of fast neutron radiation. It is predominately a function of the hydrogen content of the materials, and to a lesser degree, by other low atomic number elements such as carbon and oxygen. The presence of chemical elements such as boron, which may absorb or capture thermal neutrons, will also have some effect on the accuracy. Hydrated minerals such as gypsum or crystals such as mica may cause the largest single error. In general, a material containing hydrogen, which is not removed during an oven dry procedure, as outlined in ASTM D2216, will cause an error in the measurement.

The standard factory supplied moisture calibration is based on a water saturated silica sand standard, which is used to calibrate a working standard. The user, to correct for other materials, may alter the calibration.

THIS INSTRUMENT CONTAINS RADIOACTIVE MATERIALS, WHICH MAY BE HAZARDOUS IF IMPROPERLY USED.

HUMBOLDT recommends that users participate in a radiation safety and applications training program given by competent instructors. Where this is not possible or impractical, users should study the Radiation Safety Manual supplied with this instrument and carefully read this Instruction Manual to become familiar with the safe operation of the instrument.

A Radioactive or By Product Material License is required from an Agreement State or The US Nuclear Regulatory Commission for possession in the United States. The governments of other countries require a similar license.

Proper use of this equipment will have little effect on the total exposure of a typical operator to ionizing radiation. However, a potential danger does exist and any questions regarding this danger should be addressed to the Radiation Safety Officer within the owner's organization or other competent persons.

Any theft or other loss and accidents to the equipment, which may involve the sealed sources of radioactive material, must be immediately reported to the Radiation Safety Officer.

1.2 Definitions

1.2.1 Precision

A statistical variation of repetitive measurements due to the binomial distribution of radioactive decay. The value used is the standard deviation of repetitive measurements. Sixty eight percent of repetitive measurements will fall within this limit and ninety five percent will fall within twice this limit. The value is changes with density and is stated at a density of 2000 kg/m³ (125 PCF).

Precision is not a percentage of the absolute density and thus cannot be converted directly to a precision at other densities. It can be computed at other densities by obtaining the absolute count rate and slope of the count rate at other densities (see 7.3).

The precision is a function of time and varies as the square root. Increasing the count time of the measurement by a factor of four will improve the precision by a factor of two.

1.2.2 Chemical Error

An error that is caused by the variations in the chemical composition of the material being tested. Gamma attenuation is a function of the electron density of materials and is thus related to both the mass and the ratio (A/Z) of the atomic mass (A) and the atomic number (Z).

The standard factory calibration is based on the average attenuation of a theoretical material consisting of half limestone and half granite. The chemical error is the spread \pm of measurements made on these materials at a true density of 2000 Kg/m³ (125 PCF).

1.2.3 Surface Error

The error caused by surface voids. Per ASTM the error is with the Gauge flush on a smooth surface and then repeating the measurement with the Gauge elevated 1.25mm (0.050 inch) over the surface. The difference in the two values is defined as "Surface error".

In actual field use, the streaming along the base of the Gauge could not take place since a portion of the Gauge base will always be resting on the material surface and the streaming will be broken up. As a result, even under extremely adverse conditions, the error would be less.

1.2.4 Depth of Measurement

The depth of measurement defined as that depth above which 95% of measurement occurs. The balance of (5%) is determined by material below stated depth. This is an important parameter of a Backscatter type Gauge since a deeper depth of measurement reduces the error caused by surface voids.

1.2.5 Units of Measurement

Where "density" and "moisture content" are used in the SI system of measurement, the absolute units of kilograms per cubic meter are utilized. Conversions to the US Customary system have been made using pounds per cubic foot (pcf). This is a gravitational system of measurement by multiplying by 0.06243. Conversion to the SI gravitational system may be made by multiplying by 9.807 to obtain kilonewtons per cubic meter. It is common practice to refer to these units in the gravitational system as "unit weights" and to those units in the absolute system as "densities".

1.3 Specifications

1.3.1 Density Measurement at 2000 kg/m³ (125 pcf)

Backscatter Density

		SLOW 4 min	NORMAL 1 min	FAST 15 sec
Precision	kg/m ³ (pcf)	± 4 (0.25)	± 8 (0.5)	±16 (1.0)
Chemical Error	kg/m ³ (pcf)	±40 (2.5)	±40 (2.5)	±40 (2.5)
Surface Error	kg/m ³ (pcf)	- 48 (3.0)	- 48 (3.0)	- 48 (3.0)
Depth	mm (inch)	88 (3.5)	88 (3.5)	88 (3.5)

Direct Transmission Density at 150 mm (6 inch)

		SLOW 4 min	NORMAL 1 min	FAST 15 sec
Precision	kg/m ³ (pcf)	± 2 (0.13)	± 4 (0.25)	± 8 (0.5)
Chemical Error	kg/m ³ (pcf)	±16 (1.0)	±16 (1.0)	±16 (1.0)
Surface Error	kg/m ³ (pcf)	- 8 (0.5)	- 8 (0.5)	- 8 (0.5)
Depth	mm (inch)	50 to 300 (2 to 12)	50 to 300 (2 to 12)	50 to 300 (2 to 12)

1.3.2 Moisture Measurement at 160 kg/m³ (10 pcf)

		SLOW 4 min	NORMAL 1 min	FAST 15 sec
Precision (pcf)	kg/m ³	± 2 (0.13)	± 4 (0.25)	± 8 (0.5)
Surface Error	kg/m ³ (pcf)	- 4 (0.25)	- 4 (0.25)	- 4 (0.25)
Depth (inch)	mm	100 to 200 (4 to 8)	100 to 200 (4 to 8)	100 to 200 (4 to 8)

1.3.3 Calibration Method

The Gauges are calibrated in accordance with the method recommended by ASTM D6938, D7759, D2950 and AASHTO 310. Five density standards consisting of three metallic blocks of Magnesium, Magnesium/Aluminum and Aluminum and two mineral blocks of Granite and Limestone to cover the measurement range of 1100 to 2700 kgm³ (70-170 PCF). The density of these standards has been determined to an accuracy of better than ±0.1 %. The working moisture standard has been calibrated against saturated silica sand with an accuracy of better than ±0.5 % to cover the measurement range of 0 to 640 kgm³ (0-40 PCF).

Four entirely different calibrations are available to the engineers or technicians controlling the use of the Gauge but they are not accessible to the operator without use of a password. Two of these are adjustments to the main calibrations to compensate for materials widely different from normal soils. No additional equipment is required for the adjustment other than a sample of the material at a known density. No additional equipment is required for an entirely new calibration other than a suitable set of standards.

Count rate data is converted to densities using USNIST gamma attenuation coefficients and the known density of the standards.

1.3.4 Field Data Conversion

Wet Density	and	% Compaction (Marshall)
Dry Density	and	% Compaction (Proctor)
Moisture Content	and	% Moisture
Void Ratio	and	% Air Voids

1.3.5 Radiological

Gamma Source	HSI 2200063
Amount and Type of Material	0.37GBq (10mCi) Cesium 137
Special Form Registration	USA/0356/S-96

ISO / ANSI Classification	ANSI 77C66535
Neutron Source	HSI 2200067
Amount and Type of Material	1.38GBq (40mCi) Americium-241:be
Neutron Yield	90 knps (nom)
Special Form Registration	CZ/1009/S-96
ISO / ANSI Classification	ANSI 77C66545
Surface Dose Rate	18.7 mrem/hour maximum
Transit Case	DOT 7A, Type A, Yellow II Label, 0.2 TI

A Radioactive or By Product Material License is required from an Agreement State or The US Nuclear Regulatory Commission for possession in the United States. The governments of other countries require a similar license

1.3.6 Electrical Specifications

Displays:	TFT; Normal Black, Sunlight Readable with backlit, 640x480 Resolution
Timer Stability:	0.01% Power Supply
Stability:	0.10%
Power Source:	Six alkaline AA size batteries
Power Consumption:	Battery life is only an estimate, power settings and individual operation of the gauge will greatly affect the life of the batteries

Processor:

Idle:	1.7 mA @ 8 volts 13.6 milliwatts 1470 Battery Life
Active:	32 mA @ 8 volts 255 milliwatts 78 Battery Life

Power Protection: Resettable Fuse

Short Circuit Proof

Auto Alarm for low battery condition

Auto shutoff for dead battery condition

1.3.7 Mechanical Specifications

1.3.7.1 Materials

Source Rod:	440C Stainless Steel, induction heat-treated to 55 Rockwell C.
Index Rod:	7075 Aluminum, hard coated and PTFE impregnated.
Gauge Base:	Machined 6061-T6 Aluminum, hard coated and PTFE-impregnated.
Post and Frames:	Machined 6061-T6 Aluminum, anodized for anti-corrosion.
Top Shell:	Injection Molded Noryl.
Bearing:	Relieved bronze with neoprene seals.
Screws/fittings:	Stainless/brass, no steel.
Operating Temp.:	10 to 70 °C, 175 °C Test Material Surface.
Storage Temperature-	55 to 85 °C

Humidity: 98% without condensation, Rain proof construction.

Vibration: 2.5 mm (0.1 in) at 12.5 Hz

Shock Unpadded: Gauge meets USDOT 7A without transit case.

1.3.7.2 Gauge

Size (excluding handle): 400 x 220 x 140 mm (15.75 x 8.66 x 5.5 in)

Height (with handle): 450 or 550 mm (18 or 21.6 in)

Weight: 13.6 kg (30 lbs.)

1.3.7.3 Reference Standard

Size: 350 x 200 x 75 mm (25 x 7.8 x 3 in)

Weight: 4.5 kg (10 lbs.)

1.3.7.4 HS-5001 Series Transit Case

Size: 600 x 495 x 356 mm (26 x 14 x 19.5 in)

Weight: 11.8 kg (26 lbs.)

1.3.7.5 Zippered Accessory Case (loaded)

Size 500 X 250 X 125 mm (19.7 x 9.8 x 5 in)

Weight 8.2 kg (18 lbs.)

1.3.7.6 Total Shipping

Weight 41 kg (89 lbs.)

1.3.8 Accessories

Transit Case

Reference Standard

Operator's Manual

Radiation Safety Manual

Source and Case Certification

Wipe Test Materials

Zippered Accessory Case

Rod Guide/Scraper Plate

Drill Rod

Four Pound Hammer

Rod Extraction Tool

2 Equipment Description

Before using this equipment, the operator should be thoroughly familiar with the Radiation Safety Manual supplied with the instrument. If possible, a suitable course in the safe use and field application should be attended.

Users who desire knowledge regarding the theory of operation of the equipment should refer to Section 7.0. This information will be helpful in understanding, the limitations of the equipment and how to avoid or work around these limitations.

2.1 Zippered Accessory Case

Zippered Accessory Case Containing:

Rod Guide/Scraper Plate

Drill Rod

Four-Pound Hammer

Rod Extraction Tool

The accessories may be carried in the transit case or may be carried in a zippered canvas bag. It is convenient to carry and decreases the bulk and weight of the transit case, which contains the Gauge, Reference Standard and Manuals.

2.1.1 Scraper Plate / Rod Guide

When the Gauge is to be used on soil, the Scraper Plate is used to smooth the site to eliminate as many surface voids as possible. Two convenient handles are located so that it may be used to scrape away loose material.

The two handles are also used as a guide when driving the rod into soil or soil aggregates for a direct transmission density measurement. The operator or a helper can stand on the plate to prevent it from shifting while the rod is hammered.

The plate is the same size as the Gauge base, and if the rod is used to mark lines around it, then the Gauge can then be approximately located over the rod hole before attempting to lower source rod into the hole.

The plate may be used to lightly tamp soil or native fines that may have been used to fill the surface voids. It should not be used with the hammer to pack soil since it may distort the plate and cause erroneous measurements.

2.1.2 Drill Rod

The Drill Rod is a medium hardness tough steel and has a captive head to allow it to be driven into soil or soil aggregates so that the source can be placed into the material for a direct transmission density measurement. The rod is marked so that the depth can be controlled by reference to the top of the Scraper Plate handle.

Use of the rod in stiff clays may require the application of the extraction tool for removal. It must not be driven or moved sideways as this will enlarge the hole or modify the density of the material being tested.

The rod is expendable and must be replaced after extensive or severe use. Repeated hammering of the cap may cause metal chips to break away and the operator and others close by the test site must wear safety glasses

2.1.3 Four-Pound Hammer

The hammer is supplied to drive the rod into soils or soil aggregates, and it may be used with the extraction tool to help remove the rod from clay. It is sufficiently heavy for this purpose and a larger hammer is not needed since it could rapidly damage the Drill Rod.

2.1.4 Extraction Tool

This tool is used to assist the removal of the Drill Rod if it becomes stuck in clay or granular material. The usual problem is a vacuum, which can exist in the hole when attempting to pull the rod out.

It does not have to be put into place before driving the rod. A slot in the middle is placed on a square, which is cut in the Drill Rod head. The arms may then be used to rotate the rod and will make it easier to extract by supplying handles to pull up on the rod. If necessary, the hammer may be lightly topped on the underside of the tool to drive the rod up out of the hole.

2.2 HS-50001 Transit Case

Containing: Gauge
Reference Standard
Operator's Manual

Radiation Safety Manual

Both the Gauge and the Transit Case are supplied with locks and they should be secured when the instrument is not in use or attended.

When stored, the equipment should be placed in a locked room or area, which is dry and maintained at a livable temperature. Storage below 20°C should be avoided and temperatures above 30°C for extended periods of time will deplete the batteries at a rapid rate and shorten their useful life.

2.2.1 Transit Case

The Transit Case is a rotational molded high strength, plastic case and is equipped with a lockable latch. The design and components follow the standard ATA case configuration that is in popular use for air shipment of delicate instruments. It has fitted compartments for the Gauge, Reference Standard and accessories along with a storage area for engineering notebooks and manuals.

It has been tested to US DOT 7A Type A requirements and has labels, which meet both International and US requirements, for surface and air cargo shipment.

2.2.2 Reference Standard

The Reference Standard is used to provide a standard count to account for aging of the calibration. Instruments, which use radiation to perform measurements, are subject to decay of the source (2.3% per year for Cs 137) drift of the detectors due to leakage and absorption of quench gas, and long-term drift of the electronics. To decrease the effect of these errors, the calibration is made as a ratio to a standard measurement. The moisture count is a ratio to a moisture count on the standard and the density count is a ratio to a density count on the standard.

The hydrogen in the reference standard determines the moisture standard count. The density standard count is determined primarily by the shielding material in the base of the Gauge and only slightly by the Reference Standard.

The Reference Standard is serialized to match the Gauge and they must not be interchanged between Gauges or moisture measurement errors may exist

2.2.3 Gauge HS-5001EZ-2

The HS-5001EZ-2-type Gauge utilizes an alphanumeric LCD touch screen, state of the art electronic circuits to generate the necessary timing circuit, and power supplies. The processor automatically compensates for the abnormal gamma attenuation coefficient for hydrogen as compared to the values of higher atomic numbered materials found in soils. Using the current standard count, it also compensates for the decay of the Cesium source. It also allows the operator to enter a correction factor (KVAL) to

compensate for hydrogen found in construction materials, which is not represented by water.

The lettering is embedded in the plastic overlay and is not harmed by water or abrasion. Since there are many functions available, a description of the purpose for each key is necessary.

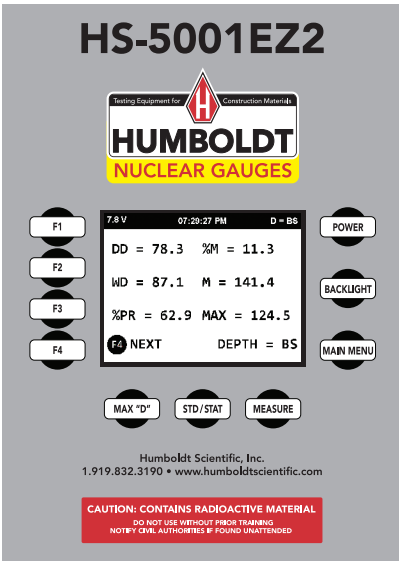
NOTE: The HS-5001EZ2 will come equipped with one of two different style base plane motherboards. When you first receive your new HS-5001EZ2 the main power will be turned off for shipping. When removing the front panel, you will see either a **BLUE**, or a **BLACK** style motherboard. To power up the base plane the blue motherboard will have a two-position switch located above the battery holders. Flipping the switch to the right towards the ribbon cable will turn on the power. The black motherboard will have a three-position switch located at the center top of the board. Sliding the switch to the bottom most position will power up the base plane. The center position is the off position, the top position is not used in the HS-5001EZ/2 gauges. This provision will be for future use.

BLUE PCB SWITCH = LEFT-OFF / RIGHT-ON

TOP – NOT USED

BLACK PCB SWITCH = MIDDLE – OFF

BOTTOM - ON



Control panel image is shown indicating the positions of the display and keys. The keys are grouped across the bottom for easy access and the display labeled for clarity.

2.2.3.1 Auto Depth Indication

The Gauge will indicate the position of the handle (source location). The method used is totally enclosed and not subject to wear by abrasive materials on a job site. It should be as reliable as any other part of the Gauge and not require periodic replacement. In case of failure, an alternate manual method of indicating the depth to the microprocessor is available.

2.2.3.2 Data Storage and Dumping

The Gauge has a micro-SD card 2GB. It will store complete field tests including date, time, project number, station, offset, and all the measurement data including standard and measurement counts, depths, soil / asphalt / nomograph and any corrections applied to factory calibrations.

This data can be dumped to a USB, which provides a convenient way to capture test data and take it with you, as well as provide an easy way to upgrade the gauge's firmware. Firmware upgrades will be available via the internet from our website.

2.2.3.3 Front Panel and Keypad

All data entry, function selections, and other options are available via a 10 key membrane keypad at the front panel. Each time a key is pressed, a short beep indicates that the key press has been recognized. The key must be pressed and released for the action to take place.

Each key can have multiple actions, corresponding to the currently selected instrument function. The actual functions are all described in Section 3 Field Operation.

On/Off (Power)



When the **POWER** key is pressed the Gauge powers up, and then runs through self-test routines. The battery test included in the self-test routines is also performed at various times in use (transparent to the operator) so that constant monitoring of battery condition is done. After this test, the Gauge condition at the time of the last use is loaded from memory. If it was turned off with an active measurement in the registers, the measurement is recalled.

Backlight

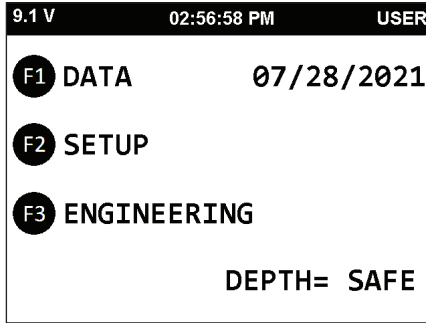


When the **BACKLIGHT** key is pressed, the display panel lights up, for night viewing. Pressing the **BACKLIGHT** key again will toggle the light off.

Main Menu



Pressing the **MAIN MENU** key will back up one sub-menu at a time. Long pressing the key 3 seconds will return to the main menu. The main menu screen will be displayed as:



Function Keys



The HS-5001EZ-2 features four function keys, **F1** through **F4**, for each one of the display lines. With few exceptions, each key is assigned a unique task specific to its assigned menu. For simplicity, tasks common to each menu will be represented, when and where possible, consistently in sublevel menus with matching graphical representations and locations. A line with an (**F1- F4**) indicates an action function line.

Maximum Density



The **MAX "D"** key allows entry of information pertaining to characteristics of the material under test. MAX D is the target density for percent compaction.

For soil, it is normally a value based on a laboratory Proctor test. For asphalt, it is a value based on a laboratory Marshall density or maximum theoretical density. The value set into this register must never be set to a value outside the range of normal soil or asphalt densities. Anything between 900 kg/m^3 (56 PCF) and 3000 kg/m^3 (200 PCF) will not cause processor errors.

It must never be set to 0.0.

Standard/Statistical

A circular icon with a black background and a white border. Inside the circle, the text "STD / STAT" is written in white, uppercase letters, centered within a white rounded rectangle.

The STD / STAT key initiates a 4- or 16-minute count of both the moisture and density channels when the handle is in the SAFE position.

It retains the values so that they can be used to ratio all the subsequent measurement counts.

Measurement

A circular icon with a black background and a white border. Inside the circle, the text "MEASURE" is written in white, uppercase letters, centered within a white rounded rectangle.

This key initiates a measurement using a 4-minute, 1-minute or 0.25-minute periods as previously selected. The actual counts are displayed on the screen and the time remaining during the measurement. After completion of the measurement, the dry density (**DD**), wet density (**WD**), moisture (**M**), percent moisture (**%M**), percent proctor (**%PR**) are displayed, if the Gauge is in the soil mode. Wet density (**WD**) or total density, % Marshall (**%MA**) if in the asphalt mode. Any of the other parameters may be successively obtained by pressing the appropriate key.

Field Operation

This chapter will describe the proper use of the equipment during the process of making field measurements on soils, soil aggregates, treated bases, or asphaltic concrete. It is assumed that the user has read the previous chapter and understands the functions of the various keys. The operator should have had training in radiation safety or thoroughly read the **RADIATION SAFETY MANUAL** supplied with this instrument and understand the basic principles of minimizing his/her exposure.

3.1 Transportation of the Equipment

The Gauge and Reference Standard should be transported in its Transit Case, which is designed for this purpose. The Gauge lock and the Transit Case lock should be in place and secured. In case of an accident to the vehicle, the locks prevent unauthorized access to the radioactive material and the case will help protect the equipment from damage. The Zippered Accessory Case will prevent loss of its items and if an automobile is used, it will protect the trunk space.


If transport is made by automobile, the Transit Case and Gauge should be placed in the trunk to keep it as far away from passengers as possible. Van location should be toward the rear and the case secured to prevent shifting. In open trucks, means must be taken to prevent shifting and unauthorized removal.

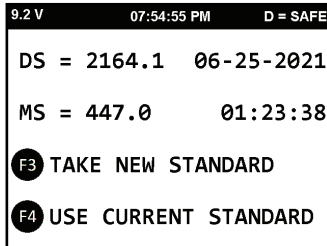
3.2 Standardization of the Gauge

Prior to use of the Gauge, a set of **STANDARD COUNTS** must be taken and used for all of the measurements to be made on a particular day. These counts should be logged for verification of proper operation and provide a history for service if required, Remove the Gauge lock and make certain that the handle is latched in the "SAFE" position. It must be in the top position of the index rod.

Important notice: The Reference Standard and bottom surface of the Gauge must be clear of any debris that would prevent the Gauge from seating firmly on the Reference Standard. Place the Reference Standard on compacted material, place the Gauge on the Reference Standard with the handle end of the Standard away from the operator. The Gauge must be seated inside the guide rails along the edges of the Standard, and the back of the Gauge up against the handle of the Reference Standard.

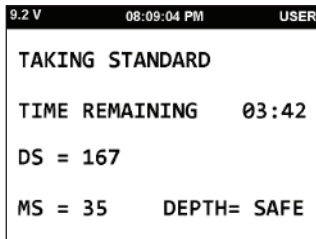
To begin the standard counts procedure from the main menu display, or from any other menus.

Press  the display will show:

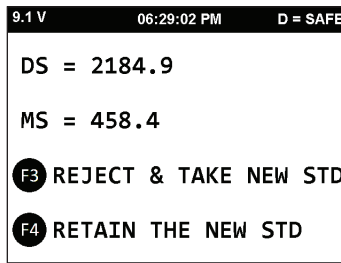


Where **DS** and **MS** are the values of the last density and moisture standard take on date **MM/DD/YYYY** and time **HH:MM:SS**. If another standard is required press **F3**, otherwise press **F4** to use the current standard and go back to the main menu.

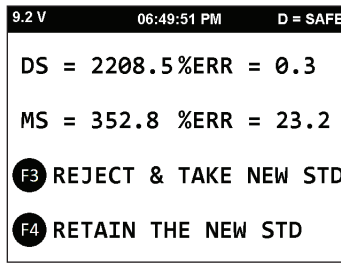
If taking a new standard, the display will show the following screen:



After the standard count completion and there are no errors in the standard counts, the display will show:



Otherwise, the display will show the density and the moisture counts with percentage errors as seen here:

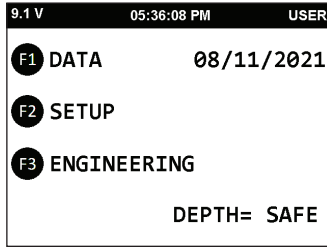
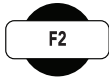


Errors within 1% for density and 2% for moisture counts are expectable. If the errors are outside these limits refer to **Important notice** above. If the above conditions are normal, then press (**F4 RETAIN AND TAKE NEW STANDARD**) and take a new standard as above in 3.2. Repeat taking new standard for a maximum of four times, or until the error is reduced to within the limits.

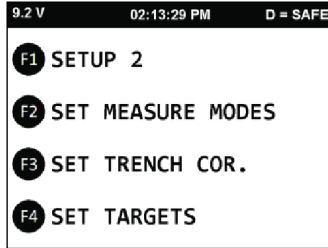
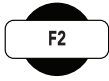
There are two methods of taking the **Standard Reference** count. The quickest is using the above procedure, which takes four minutes. The four-minute counter indicates the amount of time remaining before the end of the count. At the end of four minutes, the two count values are stored in the **DS** and **MS** registers.

The second method is the **Statistical Standard** test. The Gauge will take 16 one-minute counts and store each 1-minute value. After 16 minutes, the averages of the 16 counts are stored in the DS and MS registers. A statistical test would then have been run on the 16 individual counts and an "R" value displayed for both DS and MS. These values should fall between 0.5 and 1.5. If they are only slightly out, another test may be taken, but if the value is greatly outside the 0.5 to 1.5 limits, service is needed. To run the statistical standard test:

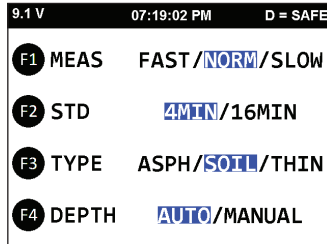
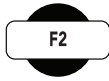
From the main menu, press **F2** to enter the **SETUP** menu as displayed:



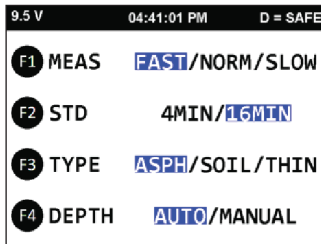
Press **F2** to enter the **SET MEASURE MODES** menu.



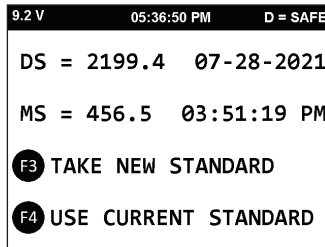
The display will be shown below with the "4MIN" highlighted. Press **F2** to toggle between "4MIN" and "16MIN".



When "16MIN" is highlighted, press **STD/STAT**.



The display will now show the screen below



9.2 V 05:36:50 PM D = SAFE

DS = 2199.4 07-28-2021

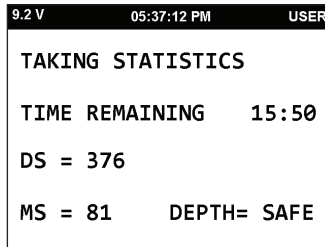
MS = 456.5 03:51:19 PM

F3 TAKE NEW STANDARD

F4 USE CURRENT STANDARD

DS and **MS** are the values of last density and moisture standards taken at the date **MM/DD/YY** and time **MM:HH:SS**. If you wish to take another standard press **F3**, otherwise press **F4** to use the current standard and go back to the main menu.

If a new a standard is being taken, the display will show as:



9.2 V 05:37:12 PM USER

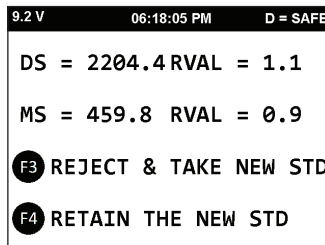
TAKING STATISTICS

TIME REMAINING 15:50

DS = 376

MS = 81 DEPTH= SAFE

After the **STAT** test is complete, and there was no error in DS & MS the display will show:



9.2 V 06:18:05 PM D = SAFE

DS = 2204.4 RVAL = 1.1

MS = 459.8 RVAL = 0.9


F3 REJECT & TAKE NEW STD

F4 RETAIN THE NEW STD

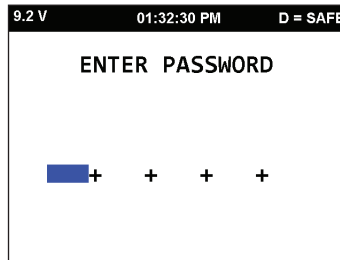
The average values of the 16 counts will remain in the **DS** & **MS** registers.

NOTE: If the handle had been moved or a key been pressed during the count routine, the counts would have been aborted and an error message will be displayed as:



Press  to clear the error condition and start over.

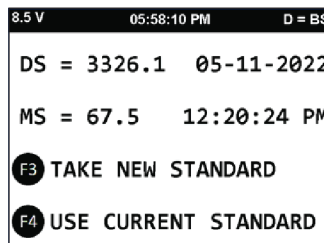
The 16-Minute **Statistical Standard** test can also be performed at different depths if required. Set the rod to the desired depth first and press **STD/STAT**, the following password screen will appear:



To enter the password, press the following function keys in sequence, **F3+F3+F3+F4+F4**.

Note: Once the correct password has been entered, the menu will remain unlocked until the power has been cycled.

After the password has been entered the following screen will appear. Using the same methods as described previously, the new standard counts can now be taken.



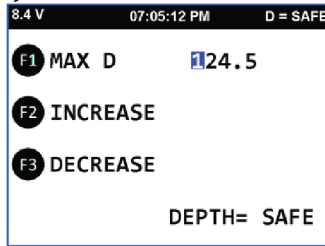
3.3 Entry of Pre-Test Data

While not required to make simple moisture and density measurements, certain parameters of the material must be entered to utilize the full potential of the HS-5001EZ-2 Gauge.

3.3.1 Maximum Density

For any type of material, the maximum density is required to calculate the percentage of compaction. For soils, this is normally a laboratory Proctor density and for asphaltic materials, the Marshall or a maximum density is used. The degree of compaction is based on a percentage of the proctor (%PR) and is a function of the measured dry density that is obtained from the result screen after a successful measurement. For asphaltic materials, the percentage of the Marshall (%MA) is a function of the wet density or total density.

Press  the display will show as:



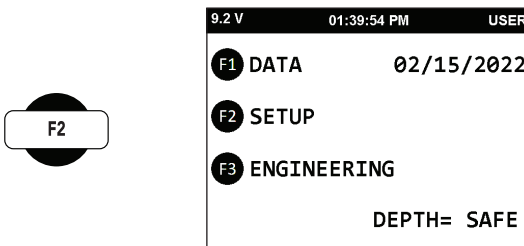
The current value of the maximum density target will be displayed and the left most field will be highlighted. Press **F1** to cycle the highlighted cursor to the right by one field at a time. Pressing **F2** will **INCREASE** the value that is highlighted, while pressing **F3** will **DECREASE** the highlighted value.

3.3.2 Moisture Correction Factor (%KVAL)

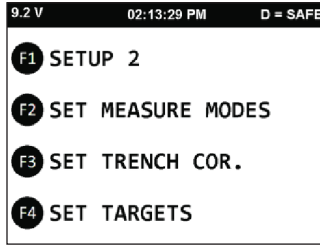
KVAL is a correction factor to be applied to the moisture measurement to account for hydrogen in the material that is not water, or water that was not removed by normal oven drying methods. A value of -1.00 would reduce the computed percent of water by roughly 1%. Typical values are between -1.00 and +2.00. If unknown, always set the value to 0.0.

To set a new value, from the **Main menu** screen as shown below:

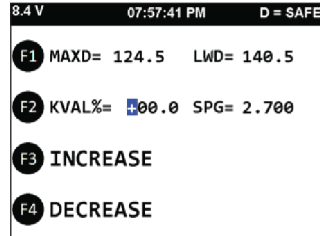
Press **F2** to enter the **SETUP** menu.



Press **F4** to enter the **SET TARGETS** menu.



From the **SET TARGETS** menu, Press **F2** to edit the **KVAL%** with the “+” highlighted as shown.



Pressing **F2** will shift the highlighted cursor one field to the right and allow the user to edit the highlighted value. Press **F3** to **INCREASE** the highlighted value, otherwise press **F4** to **DECREASE** the value.

The value entered will affect the computed values of **MOISTURE CONTENT (M)**, **DRY DENSITY (DD)**, and **PERCENT MOISTURE (%M)**. There are three methods of determining the proper value of **KVAL** to be used:

- (A) If tests can be run in the field with **KVAL** set on zero and samples of the material taken from under the Gauge. Laboratory oven dry can be used to compute the correct value of **KVAL**. The average of four or more samples is advisable in order to decrease statistical errors in the Gauge and oven dry errors due to mishandling of the material.

The equation is:

$$\text{Kval} = \frac{\% \text{ M (Oven)} - \% \text{ M (Gauge)}}{\% \text{ M (Gauge)} + 100} \times 100$$

- (B) If laboratory facilities are not available, the tests can be run using other methods of determining percent moisture. The same equation may be used or the value of **KVAL** can be determined by systematically changing the stored value of **KVAL** until the correct **PERCENT MOISTURE** is computed by the Gauge while retaining the same measurement data in memory.
- (C) If no other method is available to verify the Gauge moisture calibration, the **PERCENT AIR VOIDS** may be utilized to determine if major

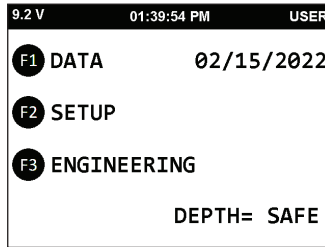
errors exist. Well-compacted soils should have PERCENT AIR VOIDS between 2.0% and 5.0% depending on gradation. If a result of the void content is negative, it is evident that the Gauge is measuring an excessive amount of water and a more negative value of KVAL should be used.

3.3.3 Specific Gravity (SPG)

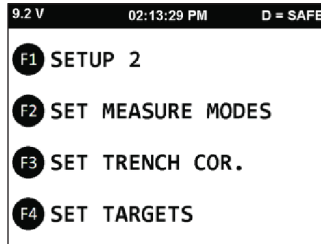
SPG is the specific gravity of solids and is obtained by a hydrometer, or other tests. The normal range for soils or aggregates will be between 2.6 and 2.75. If no accurate value is known, use 2.700. The specific gravity of the measured material solids is required to compute the VOIDS RATIO (**VR**) or PERCENT AIR VOIDS.

To set a new value, from the **Main menu** screen.

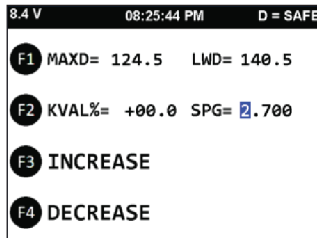
Press **F2** to enter the **SETUP** menu.



Press **F4** to enter the **SET TARGETS** menu.



From the **TARGETS** menu, Press **F2** until the first field of the **SPG** value is highlighted as shown:



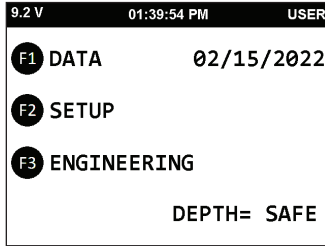
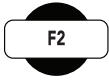
Pressing **F2** will shift the highlighted cursor one field to the right to allow the user to edit the highlighted value. Press **F3** to **INCREASE** the highlighted value, otherwise press **F4** to **DECREASE** the value.

3.3.4 Density of Underlying Materials (LWD)

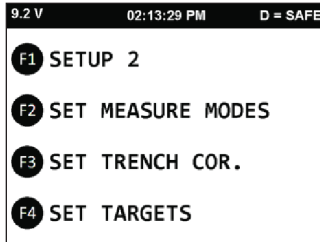
LWD is the density of the underlying material when the nomograph method (THIN MODE) is used to compute the density of thin layers. Any reasonable value may be entered.

To set a new value, from the **Main menu** screen.

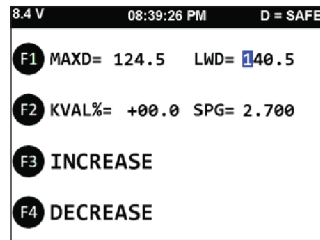
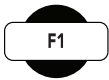
Press **F2** to enter the **SETUP** menu:



Press **F4** to enter the **SET TARGETS** menu.



From the **Targets** menu, Press **F1** until the first field of the **LWD** value is highlighted as shown:



Pressing **F1** will shift the highlighted cursor one field to the right to allow the user to edit the highlighted value. Press **F3** to **INCREASE** the highlighted value, otherwise press **F4** to **DECREASE** the value.

3.4 Site Selection

In general, all measurement should be made as soon as possible after the site has been compacted. This is particularly true for fills and embankments since evaporation may dry out the surface material and lower the average moisture measurement. Any rain prior to the measurements may increase these values unless sufficient time has elapsed to allow surface drying.

These conditions may be alleviated by removing surface materials to a depth necessary to eliminate non-homogeneous materials.

For asphaltic concrete emplacements, the testing should ideally be made while the material is being compacted so that additional rolling can be accomplished before the material cools below acceptable compaction temperatures.

The selection of a site to be measured is left to the judgement of the operator or may be defined by prescribed procedures or specifications. A random sampling method is recommended.

An optionally selected site should not be chosen on obvious conditions which may either reject or pass the results. It should be representative of the total area to be tested.

3.5 Site Preparation

Any site to be measured should be clear of all loose debris before attempting to seat the Gauge. After removing the loose material from soils, the area should be leveled using the Scraper Plate to provide a flat surface. Any large surface void areas should be filled with native fines even though a direct transmission measurement will be made.

If hard surfaced areas are involved which make the direct transmission method impractical or impossible, then a backscatter measurement will have to be made. In addition, the surface voids must be carefully leveled with mineral filler and lightly compacted with the Scraper Plate to minimize surface errors.

The Scraper Plate is used as a guide for the Drill Rod to facilitate making a vertical hole. Place the Scraper Plate over the desired site and while holding it in place with one foot, drive the rod to a depth at least 50 mm (2 inches) deeper than the measurement depth. The Drill Rod is marked in 50mm (2- inch) increments to aid in judging the depth. Safety Glasses must be worn to prevent eye damage while striking the rod with the hammer.

If the Drill Rod cannot be easily removed from the hole, place the Extraction Tool around the rod and engage the flat surfaces at the bottom of the head.

Using the tool, rotate and pull on the Drill Rod to remove it. If the Drill Rod is still difficult to remove, lightly tap on the bottom surface of the Extraction Tool and drive it vertically out of the hole.

If the line is used to make a light mark is drawn around the Scraper Plate while it is placed over the hole, it will be easier to locate the Gauge such that the source rod will extend into the hole without difficulty.


3.6 Positioning the Gauge

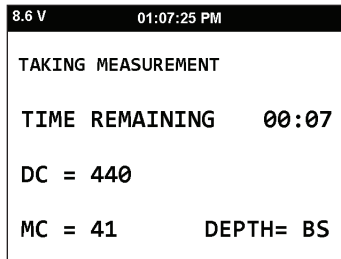
Carefully place the Gauge over the prepared site. If backscatter is used, seat the Gauge to make it as flush to the surface as possible. If a line was scribed around the site for direct transmission, then the base should be centered over the site to ease insertion of the source rod into the hole.

Release the LATCH by pressing the trigger into the handle, push the handle down until the approximate correct position is obtained, the first notch for backscatter or the correct predetermined depth for direct transmission. At the correct depth, release the trigger, and lift the handle just above the notch then push the handle one more time until hearing the “click” as the INDEXER accurately position the source.

If a direct transmission is being used, pull the Gauge toward the control panel end to force the source rod against the side of the prepared hole. This is important since avoid could exist between the rod tip and the side of the hole.

3.7 Taking the Measurement Count

Press  from any menu and the screen will be shown as below:



NOTE: If the gauge is in low power mode (Power on Screen off) when pressing the **MEASURE** key, a warm up period of about 10 seconds will elapse to bring the electronics and detector tube signals up to a stable level before measurement can begin.

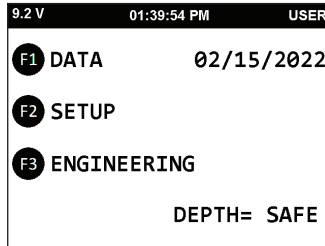
The measurement can be taken by simply pressing the **MEASURE** key. Most measurements will be made, by using the “**NORM**” in measure mode, which takes an exact one-minute count. It may be desirable to use the “**FAST**” or fifteen-Second measure mode if it is necessary to make a quick measurement to avoid conflict with compaction equipment. The measurement precision will be degraded by a factor of two.

Use of the “**SLOW**” four-minute measuring mode will enable the user to improve the precision by a factor of two. This will allow close examination of small density changes such as establishing a roller pattern or attempting to improve compaction efficiency.

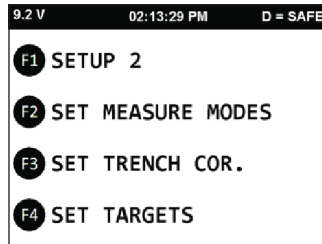
3.7.1 Measurement Time Selection

To select measurement time mode, from the main menu.

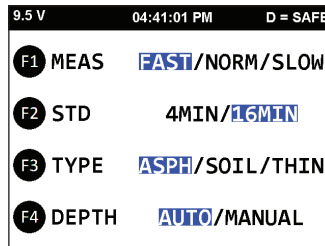
Press **F2** to enter the **SETUP** menu:



Press **F2** to enter the **SET MEASURE MODES** menu.



Press **F1** to change the **Measure** mode.



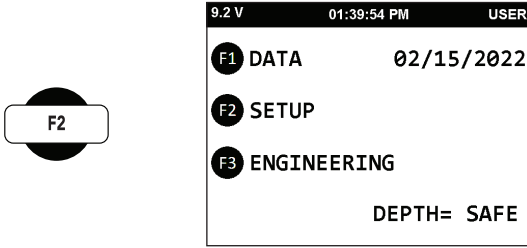
Press **F1** to advance the field to the right (**FAST / NORM / SLOW**) until the desired measurement time selection is highlighted.

3.7.2 Measurement Type Selection

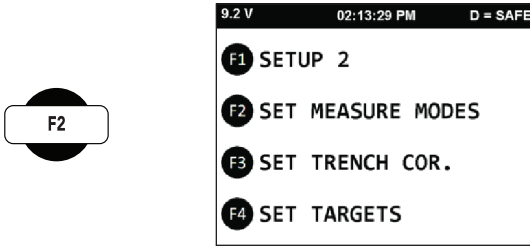
Before a measurement can be taken, the material under test must be selected i.e., (ASPHALT / SOIL / THIN LAYER).

To select measurement type, from the main menu

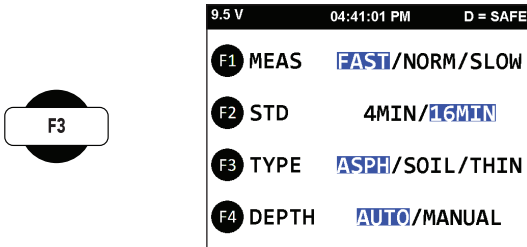
Press **F2** to enter the **SETUP** menu:



Press **F2** to enter the **SET MEASURE MODES** menu.



Press **F3** to change the **Measure** mode.



Press **F3** to advance the field to the right (ASPH / SOIL / THIN) until the desired measurement type selection is highlighted.

3.7.2.1 Asphalt Measurements

Set the mode to Asphalt as described above. Set the rod depth to the desired depth and press the **MEASURE** key. **NOTE:** Both backscatter and direct transmission may be used for Asphalt. The latter is seldom used due to the destructive nature of making the direct transmission hole.

Press **MEASURE** from any menu and the screen will be displayed as:

```
8.6 V          01:07:25 PM
TAKING MEASUREMENT
TIME REMAINING  00:07
DC = 440
MC = 41        DEPTH= BS
```

After the **TIME REMAINING** counter has elapsed. The Wet Density (**WD**) and Percent Marshall (**%MA**) will appear on the display. Since the moisture channel is measuring Hydrogen, the displayed results will approximate the Asphalt Content (**AC**) of the mix. The depth of measurement will be 100mm (4 inches) or even more depending on the actual asphalt content.

F4

```
8.7 V          12:50:52 PM    D = BS
WD = 98.2    AC = 9.2
%MA = 72.2    M = 133.2
MAX = 124.5
F4 NEXT      DEPTH = BS
```

Press **F4** to advance to the next results data screen as shown:

F4

```
8.6 V          01:13:44 PM    D = SAFE
DC = 1057.8 DS = 2192.8
MC = 95.5    MS = 464.6
VR = 0.9     %AV = 33.9
F4 LAST      DEPTH = BS
```

The Density Counts (**DC**), Density Standard (**DS**), Moisture Counts (**MC**), and Moisture Standard (**MS**) will indicate the counts used to determine the computed data. The Void Ratio (**VR**) and Percent Air Voids (**%AV**) are calculated along with the **DEPTH** at which the measurement was taken.

Press **F4** to advance to the last data screen and display a QR code to be used with the HUMBOLDT GAUGE APP.



Pressing **F4** again will cycle through the data results menus again

Move the handle back to the **SAFE** position and note that the display did not change. It is not necessary to leave the source in the measurement position (exposed) while calculations are made. So long as measurement data is present in the active registers the handle position in which the data was taken remains in the display. To clear the data press **MAIN MENU** and the display will correctly indicate **SAFE**. To view the results of the current measurement again, from the **MAIN MENU** press **F1 (DATA)**, **F1 (MEASUREMENTS)**, **F1 (CURRENT MEASUREMENT)** and the data results screen will appear again.

3.7.2.2 Asphalt Thin Layer Measurements

There are currently no available true Thin-Lift Gauges of the surface type. They all make one or two measurements at depths greater than the desired thickness and calculate the apparent density of the top layer using the varying depth response of the Gauge in the backscatter mode. The major problem with them is that the resultant precision is so poor that the validity of the results is questionable.

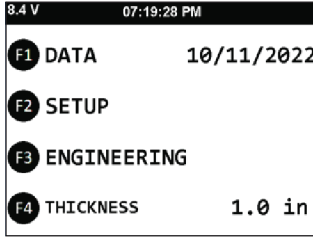
The HS-5001EZ2 Gauge uses the nomograph principle where the density of the underlying material is known from prior measurement. The top layer density is then calculated.

The density of the underlying material must be entered into the **LWD** register as described in section **3.3.4 Density of Underlying Materials**.

Next the **MEASURE MODE** must be set to **THIN** as described in section **3.7.2 Measurement Type Selection**.


The main menu screen will now display “**F4 THICKNESS**” as shown below: Press the **F4** key to set the desired thickness.

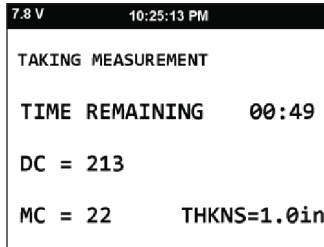
NOTE: Pressing **F4** will **INCREASE** the thickness while pressing **F4 + MAIN MENU** simultaneously will **DECREASE** the thickness.



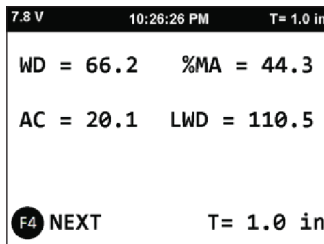
The increments are 5mm (0.2 inches) and the maximum range is from 25mm (1.0 inch) to 160mm (6.4 inches). The latter value includes 100% of the maximum response of the Gauge to density in the backscatter mode. After the desired thickness has been entered. Set the index rod to the backscatter.

NOTE: If the **AUTO** depth is set to **MANUAL** mode, **F4** on the main menu will now be replaced with “**THICKNESS**” Because Thin Mode is always measured in the Backscatter position. After pressing the **MEASURE** key, the gauge will ask you to set the depth rod to backscatter and automatically adjust internally to backscatter.

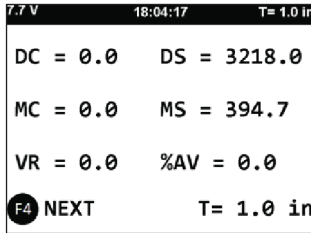
Press  and the screen will be displayed as:



After the **TIME REMAINING** counter has elapsed. The Wet Density (**WD**) of the top layer, Percent Marshall (**%MA**) and the approximate Asphalt Content (**AC**) will appear on the display.



Press **F4** to advance to the next results data screen as shown:



The depth of the measurement will be 100mm (4 inches) or even more depending on the actual asphalt content. The Density Counts (**DS**), Density Standard (**DS**), Moisture Standard (**MS**), and Moisture Counts (**MC**) will indicate the counts used to determine the computed data. The Void Ratio (**VR**) and Percent Air Voids (**%AV**) are calculated along with the Thickness (**T**) of the material tested.



Press **F4** to advance to the last data screen and display a QR code to be used with the HUMBOLDT GAUGE APP.

Move the handle back to the **SAFE** position and note that the display did not change. It is not necessary to leave the source in the measurement position (exposed) while calculations are made. So long as measurement data is present in the active registers the handle position in which the data was taken remains in the display. To clear the data press **MAIN MENU** and the display will correctly indicate **SAFE**. To view the results of the current measurement again, from the **MAIN MENU** press **F1 (DATA)**, **F1 (MEASUREMENTS)**, **F1 (CURRENT MEASUREMENT)** and the data results screen will appear again.

Thickness

mm	inch	Relative Response
0	0.0	0.000
25	1.0	0.490
50	2.0	0.778
75	3.0	0.912
100	4.0	0.960
125	5.0	0.985
150	6.0	0.998
162	6.5	1.000

The Gauge obtains its backscatter density measurement in a manner, which is non-linear with respect to the strata within the sample. The table on the next page indicates the response at various depths or thickness

Below 100mm (4 inches) the Gauge is relatively unaffected by any change in density. In fact, a large change in density below 75mm (3 inches) has very little effect.

There is always a question of when to use the nomograph method. The table below presents some information as a guideline.

Since the best accuracy that one can expect for a backscatter density measurement, even assuming corrections for chemistry, is about 2.0% then attempting to correct for the bottom layer density when it causes less than a 2% error is futile. The conditions noted within an * are ones where the nomograph correction is recommended.

Errors Due To Mat Thickness

Top Layer		% Error with no correction for % difference in density						
mm	inch	2%	4%	6%	8%	10%	15%	20%
25.0	1.0	1.0	*2.1	*3.1	*4.1	*5.2	*7.8	*10.4
37.5	1.5	0.7	1.4	*2.1	*2.8	*3.5	*5.3	*7.0
50.0	2.0	0.5	0.9	1.4	1.8	*2.3	*3.4	*4.6
62.5	2.5	0.3	0.6	0.8	1.1	1.4	*2.1	*2.8
75.0	3.0	0.2	0.3	0.5	0.7	0.8	1.2	1.6
87.5	3.5	0.1	0.2	0.3	0.4	0.5	0.7	0.9
100.0	4.0	0.1	0.1	0.2	0.2	0.3	0.4	0.6
112.5	4.5	0.0	0.1	0.1	0.2	0.2	0.3	0.5
125.0	5.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4
137.5	5.5	0.0	0.1	0.1	0.2	0.2	0.3	0.4
150.0	6.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2
162.5	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

While the table may seem confusing it simply states that, for example, one should correct for a mat thickness of 37.5mm (1.5 inches) only when the difference between the top layer and bottom layer densities is 6% or more. If the mat is 50mm (2.0 inches), then use the nomograph when the density difference is 10% or more.

Since a density difference greater than 10% is seldom encountered, one need only be concerned when the mat thickness is 50mm (2.0 inches) or less.

If field procedures involve establishing a passing density using a test strip then only relative densities are important and no corrections are necessary.

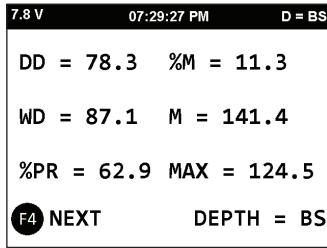
3.7.2.3 Soil Measurements

Set the mode to Soil as described above in 3.7.2 **Measurement Type Selection**.

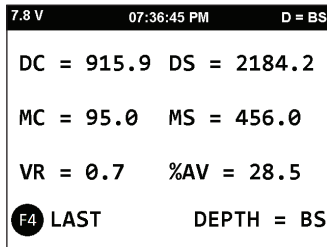
Press **MEASURE** from any menu and the screen will be displayed as:

7.8 V	07:33:55 PM
TAKING MEASUREMENT	
TIME REMAINING	00:52
DC = 120	
MC = 14	DEPTH= BS

After the **TIME REMAINING** counter has elapsed. The Dry Density (**DD**), Wet Density (**WD**), Percent Moisture (**%M**), Wet Density (**WD**), Moisture Content (**M**), and Percent Proctor (**%PR**) will appear on the display.



Press **F4** to advance to the next results data screen as shown:



Press **F4** to advance to the last data screen and display a QR code to be used with the HUMBOLDT GAUGE APP.



Pressing **F4** again will cycle through the data results menus again. The Density Counts (**DC**), Density Standard (**DS**), Moisture Standard (**MS**), and Moisture Counts (**MC**), will indicate the counts used to determine the computed data. The Void Ratio (**VR**) and Percent Air Voids (**%AV**) are calculated along with the **DEPTH** at which the measurement was taken. The latter is quite useful to assure that the moisture calibration including the KVAL used fits the chemistry of the soil. Well-compacted soil should have air voids between 3% and 5%. If the value is negative, comparative data must be run against oven dry or other acceptable methods to determine the correct KVAL. Move the handle back to the **SAFE** position and note that the display did not change. It is not necessary to leave the source in the measurement position (exposed) while calculations are made. So long as measurement data is present in the active registers the

position in which the data was taken remains in the display. To clear the data press **MAIN MENU** and the display will correctly indicate **SAFE**. To view the results of the current measurement again, from the **MAIN MENU** press **F1 (DATA)**, **F1 (MEASUREMENTS)**, **F1(CURRENT MEASUREMENT)** and the data results screen will appear again.

3.7.2.4 Soil Measurements in Trenches

Moisture measurements made in trenches are subject to error, due to water in the walls of the trench. Special software is included (Trench Correction) to compensate for this error.

Making measurements in a trench requires some precautions. Extra shielding of detectors has minimized these effects on the 5001 if a few precautions are taken.

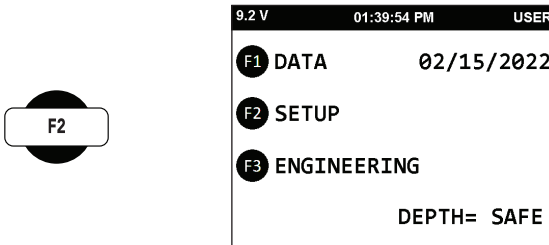
The gauge should not be used in a trench where the distance between the walls is less than 600mm (24 inches). When the standard counts are made, they should be done in the trench.

If the point to be measured is less, then 400mm (16 inches) and the reference standard should be placed in the approximate location (distance from the wall) that the measurement is to be made. The source end of the gauge should be facing the closest wall of the trench.

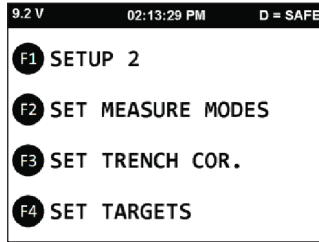
If the trench is more than 900mm (36 inches) and no measurement will be made at a distance less than 400mm (16inches) from the wall, then a normal standard counts may be used.

Set the measure mode to Soil as described above in 3.7.2 **Measurement Type Selection**. First, place the Gauge on its Reference Standard in the same location in the trench where a measurement is to be made. With the Gauge handle in the **SAFE** position.

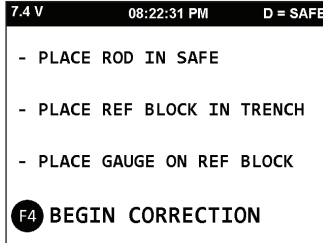
From the main menu Press **F2** to enter the **SETUP** menu.



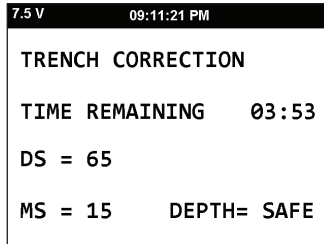
Press **F3** to enter the **SET TRENCH CORRECTION** menu.



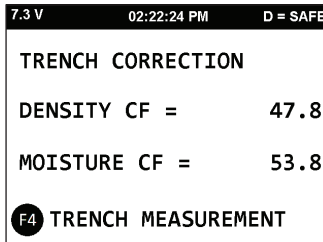
Press **F4** to begin the **TRENCH CORRECTION**



A four-minute count is started indicating that a correction is being determined to account for the water in the walls of the trench. Four minutes are used to produce a precision sufficient to determine the value otherwise the correction factor may produce an error larger than the trench error.

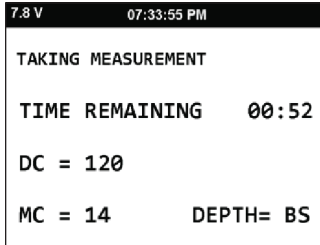


When the count is complete both the Density and Moisture Correction Factor will appear on the display, which is the difference between the Moisture Standard Count outside of the trench and the same standard inside the trench.

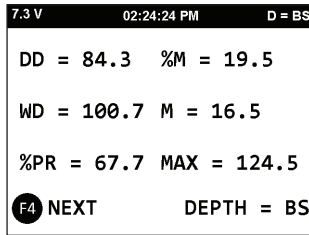


Remove the Gauge from the Reference Standard, place the Gauge on the site to be tested (always use direction transmission in a trench) and take a normal soil measurement. The measurement result has been adjusted to compensate for the water in the wall of the trench.

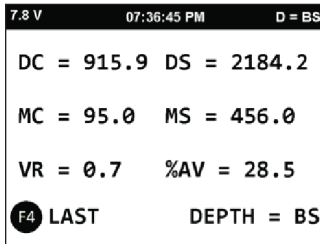
Press **F4** to begin **TRENCH MEASUREMENT** screen will display as:



After the **TIME REMAINING** counter has elapsed. The Dry Density (**DD**), Wet Density (**WD**), Percent Moisture (**%M**), Wet Density (**WD**), Moisture Content (**M**), and Percent Proctor (**%PR**) will appear on the display.



Press **F4** to advance to the next results data screen as shown:



Press **F4** to advance to the last data screen and display a QR code to be used with the HUMBOLDT GAUGE APP.



Pressing **F4** again will cycle through the data results menus again. The Density Counts (**DC**), Density Standard (**DS**), Moisture Standard (**MS**), and Moisture Counts (**MC**), will indicate the counts used to determine the computed data. The Void Ratio (**VR**) and Percent Air Voids (**%AV**) are calculated along with the **DEPTH** at which the measurement was taken.

3.8 Processing The Results

The WET DENSITY is obtained using the following equation:

$$CR = Ae - BD - C$$

Where: CR = Density Measurement Count (DC)
divided by Density Standard Count (DS)

D = Wet Density of the material
@ depth X A, B, C = Calibration Constants @ depth X

In addition, the MOISTURE CONTENT
is obtained by simply using the following equation:

$$CR = E + FM$$

Where: CR = Moisture Measurement Count (MC)
divided by Moisture Standard Count (MS)

M = Moisture Content
E, F = Calibration Constants

The DRY DENSITY is obtained by subtracting the MOISTURE CONTENT from the WET DENSITY and the PERCENT MOISTURE is obtained by dividing the MOISTURE CONTENT by the DRY DENSITY.

The processor performs the functions, which produce the results without consulting tables, or transferring data to a handheld calculator. This decreases the potential for operator error. The processor also compensates for the attenuation coefficient of hydrogen, which is vastly different from soils.

If the measurement was made on asphaltic concrete only the WET DENSITY has any meaning however, the calculated PERCENT MOISTURE will closely approximate the asphalt content of the mix.

Before actually processing data, the display must indicate the actual depth at which the measurement was made. This is set by using the "**F4**" key in the manual depth mode or automatically set by the auto-indexing network. The display will only indicate calibrated depths and the value will be in millimeters or inches as preset in the instrument.

The KVAL should have previously been placed into the processor as explained in 3.3.2.

3.8.1 Compaction Control

Generally, it is desirable to obtain compaction as a percentage of a maximum density based on a laboratory Proctor density for soils, or as a percentage of the maximum density based on a laboratory Marshall density, or other requirements for asphaltic concrete.

If the desired maximum density has been placed in the D register by using the "MAX D" key as described in 3.2.1, the PERCENT COMPACTION can be by obtained.

% PR = Percentage of the dry density to the maximum soil density.

% MA = Percentage of the wet density to the maximum asphalt density.

3.8.2 Void Ratio

By definition, the void ratio (VR) is the ratio of the volume of the void to the volume of the solids. To make this calculation, it is necessary for the processor to know the specific gravity of the solids. There are standard laboratory tests to make this determination. If the true specific gravity is not known, the value of 2.70 may be used to yield approximate void ratios.

The specific gravity may be entered as described in 3.3.3. The "VR" will perform the necessary calculations and display the result in "VR = XXX.X". No attempt is made to allow for rock corrections since the volume of larger rock is unknown.

Void ratio is an indication of the degree of compaction if the maximum density is not known.

3.8.3 Percent Air Voids

This term is defined as volume of air as a percentage of the total volume. The specific gravity of the solids must be known and have been entered as described in 3.3.3. If the calculation is made for asphaltic concrete, the normal PERCENT MOISTURE calculation for soils will have to be adjusted by using "KVAL" to agree with the asphalt content of the mix. The calculation is performed by "% AV" and the results will be displayed in "%AV = XX.XX".

"% AV" is an indication of the degree of compaction and saturation of the compacted materials. It is also a good indication of the validity of the calibration, particularly moisture, for the specific materials being tested. A negative value for "% AV" indicates that the KVAL needs to be a more negative value. A positive value of more than 5.0% may be caused by incomplete compaction or the need to increase the KVAL in a positive direction (not necessarily a positive number but perhaps less negative one).

3.9 Repackaging the Equipment

After use, secure the equipment: First, latch the handle in the "safe" position and install the padlock. After wiping the Gauge and Reference Standard to remove all soil and moisture, place them in the Transit Case and

lock the case latch. This double security is provided to prevent unauthorized access to the Instrument and possible injury. Clean the accessories and place them in the Zippered Accessory Case to prevent loss.

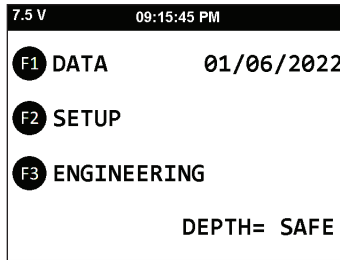
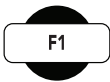
4 Menus

4.1 Data Menus

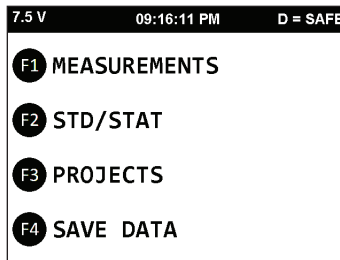
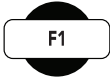
The **DATA** function key **F1** is accessible from the main menu. This will allow the users to view **MEASUREMENTS, STANDARD/STATISTICAL COUNTS, VIEW/EDIT PROJECTS, SAVE DATA, and QR CODE** for use with Humboldt Gauge app.

4.1.1 View Current Measurement

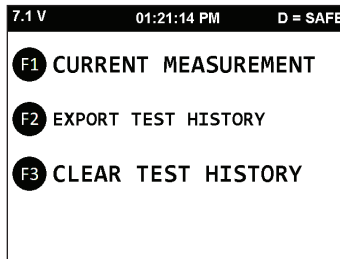
Press **F1** to enter the **DATA** menu.



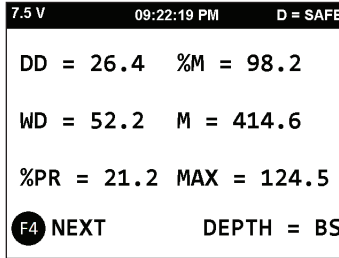
Press **F1** to enter the **MEASUREMENTS** menu.



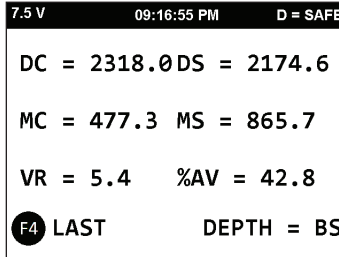
Press **F1** to display the **CURRENT MEASUREMENT**.



Press **F4** to advance to the **NEXT** result screen.



Press **F4** to advance to the **LAST** result screen.

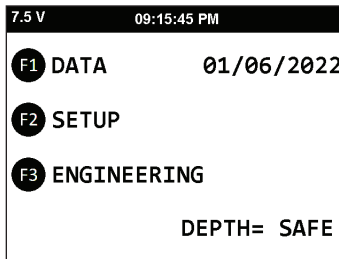
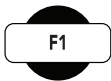


Pressing **F4** again will cycle through the menus again.

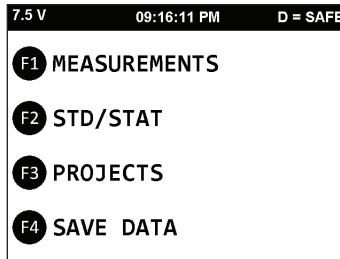
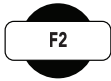


4.1.2 Current Standard / Statistical Count

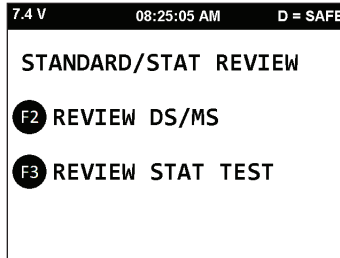
Press **F1** to enter the **DATA** menu.



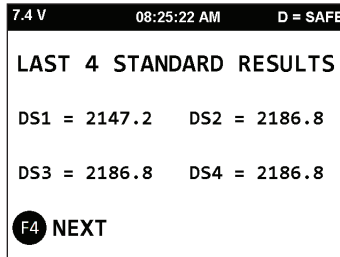
Press **F2** to enter the **STD/STAT** menu.



Press **F2** to **REVIEW DS/MS** Standards

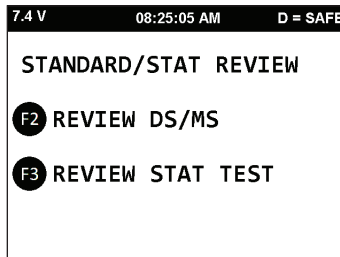
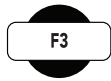


Press **F4** to cycle through the density and moisture standards.

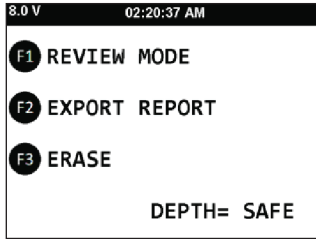
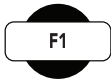


The Statistical Test Review has 3 option menus. Review, Export, and Erase.

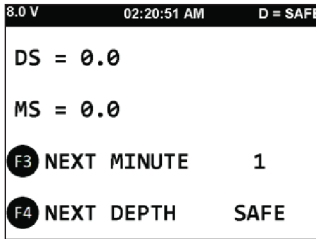
Press **F3** at the **STD/STAT** menu.



Press **F1** to enter **REVIEW MODE** menu.



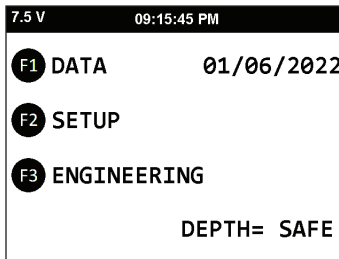
Pressing **F3** will cycle through the 16 1-MINUTE count.
Pressing **F4** will cycle through the **DEPTH** of each statistical count.



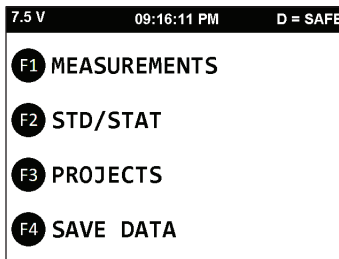
4.1.3 Projects Setup

This setup allows the entry of data pertaining to the project(s) on which the Gauge is being used. Their entry is made by first selecting the desired function which displays the current value, keying in a new value using the function keys.

Press **F1** to enter the **DATA** menu.



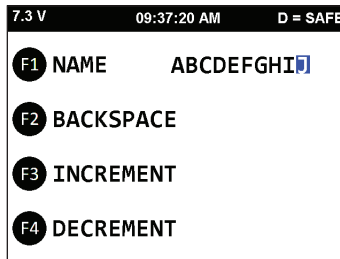
Press **F3** to enter the **PROJECTS** menu.



Press **F3** to **CREATE** a new project.



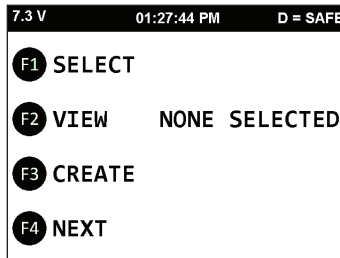
Press **F1** to advance the highlighted character one field to the right.
Press **F2** to **BACKSPACE** one field to the left.
Press **F3** to **INCREMENT** the highlighted field one character.
Press **F4** to **DECREMENT** the highlighted field one character.



After the Project name has been entered press **MAIN MENU** to **SAVE** the project.



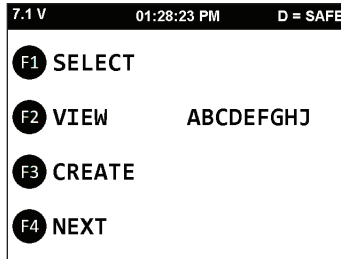
Press **F1** to **SELECT** the current project.



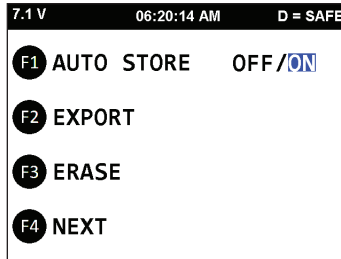
Press **F2** to move to the **NEXT** project.
Press **F3** to move to the **PREVIOUS** project.
Press **F4** to **SELECT** the desired project.



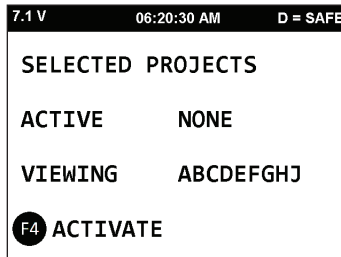
Press **F4** to advance to the **NEXT** menu.



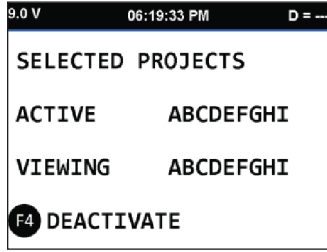
Press **F1** to turn **AUTO STORE** on or off.
Press **F2** to **EXPORT** to a USB drive.
Press **F3** to **ERASE** the current project.
Press **F4** to advance to the next menu.



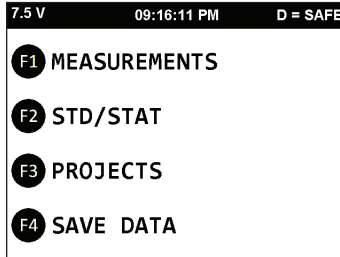
Press **F4** to **ACTIVATE** the current project.



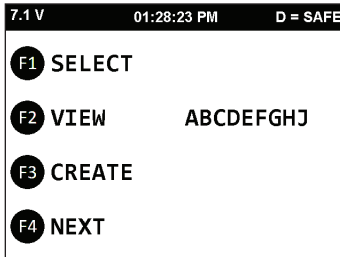
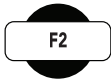
Press **F4** again to **DEACTIVATE** the project.



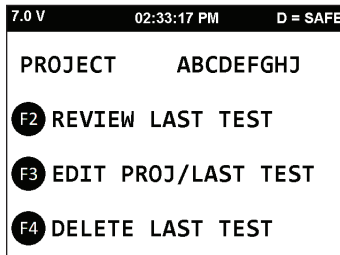
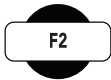
Press **F3** for **PROJECTS** from the data menu to view projects.



Press **F2** to enter the Project **VIEW** menu.



Press **F2** to **REVIEW LAST TEST** taken.

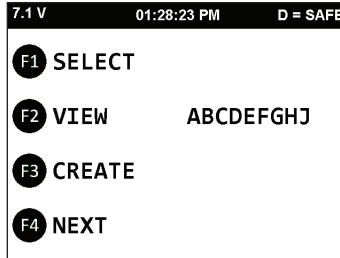
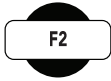


4.1.3.1 Edit Project

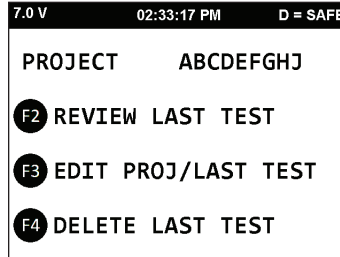
To edit a project, enter the Project **VIEW** menu as previously described.

NOTE: To be able to edit the Station and Lane parameters a Project must first be active and a test had been taken.

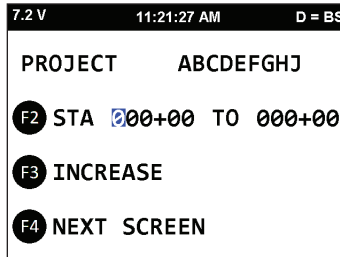
Press **F2** to enter the **VIEW** menu.



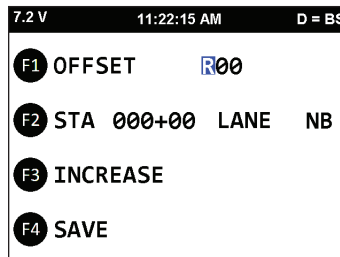
Press **F3** to EDIT the **PROJECT/LAST TEST**.



Press **F2** to shift the highlighted field to the right to edit the station.
Press **F3** to **INCREASE** the value of the highlighted field.
Press **F4** to advance to the **NEXT SCREEN**.

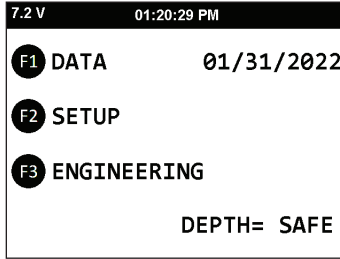
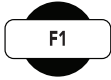


Press **F1** to shift through the **OFFSET** field values.
Press **F2** to shift through the Station and **LANE** field values.
Press **F3** to **INCREASE** the highlighted value.
Press **F4** to **SAVE** the current settings.

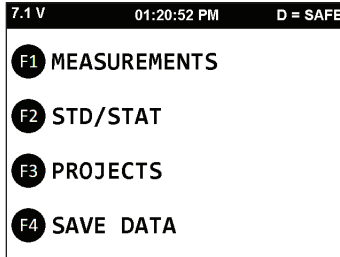


4.1.3.2 Erase Stored Project Data

Press **F1** to enter the **DATA** menu.



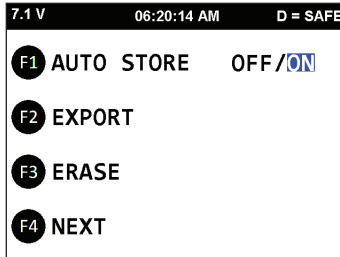
Press **F3** to enter the **PROJECTS** menu.



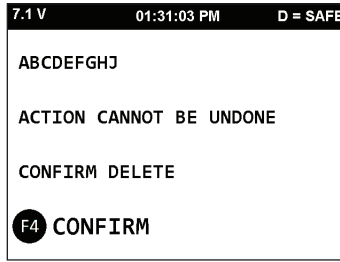
Press **F4** to enter the **NEXT** menu.



Press **F3** to **ERASE** the project.

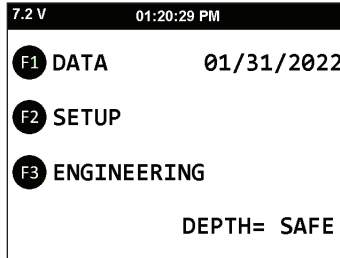
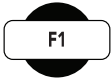


Press **F4** to confirm the **DELETE**.

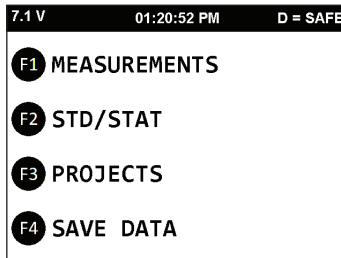
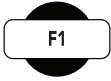


4.1.3.3 Erase Stored History Data

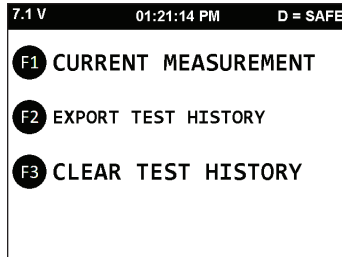
Press **F1** to enter the **DATA** menu.



Press **F1** to enter the **MEASUREMENTS** menu.



Press **F3** to **CLEAR TEST HISTORY**.



The screen will be displayed as:

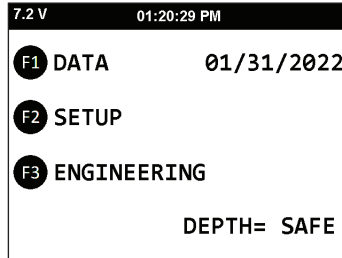


4.2 Menu Setup

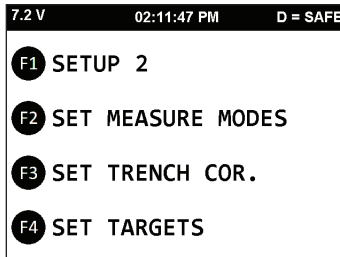
The **SETUP** function key **F2** accessible from the main menu. This will allow the users to set up **MEASURE MODES, TRENCH CORRECTION, TARGETS, DATE, TIME, DATE/TIME FORMAT, UNITS, GAUGE CUSTOMIZATION,** and **GPS SETTING.**

4.2.1 Date Setup

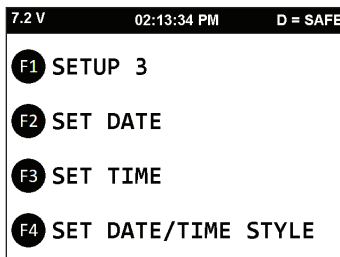
Press **F2** to enter the **SETUP** menu.



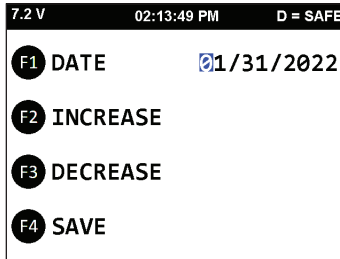
Press **F1** to enter the **SETUP 2** menu.



Press **F2** to enter the **SET DATE** menu.

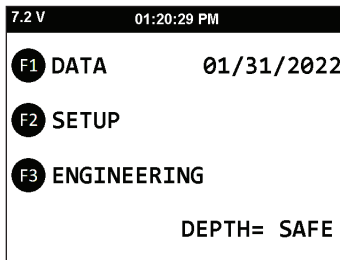
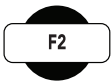


Press **F1** to shift the highlighted **DATE** field to the right.
Press **F2** to **INCREASE** the highlighted field value.
Press **F3** to **DECREASE** the highlighted field value.
Press **F4** to **SAVE** the desired date.

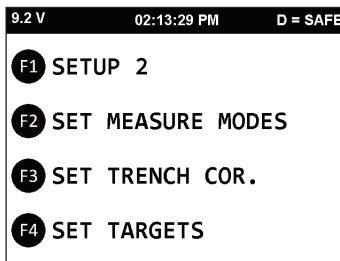


4.2.2 Time Setup

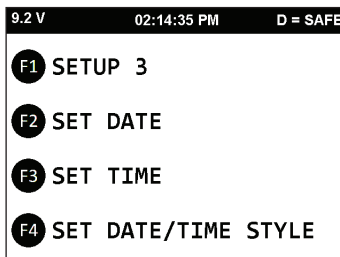
Press **F2** to enter the **SETUP** menu.



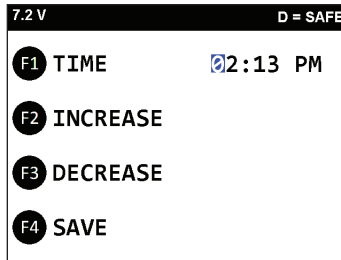
Press **F1** to enter the **SETUP 2** menu.



Press **F3** to enter the **SET TIME** menu.

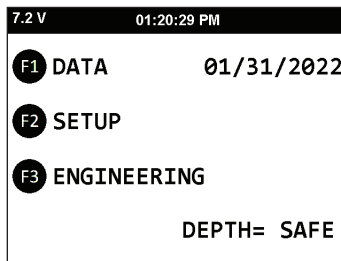


Press **F1** to shift the highlighted **TIME** field to the right.
Press **F2** to **INCREASE** the highlighted field value.
Press **F3** to **DECREASE** the highlighted field value.
Press **F4** to **SAVE** the desired time.

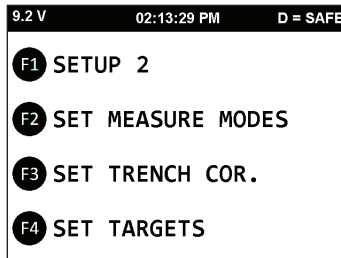
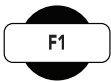


4.2.3 Date/Time Style Setup

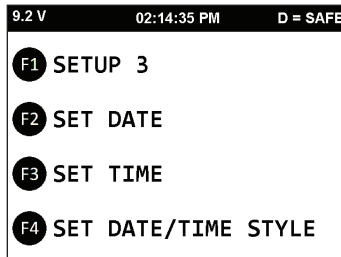
Press **F1** to enter the **DATA** menu.



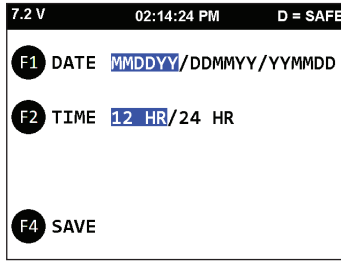
Press **F1** to enter the **SETUP 2** menu.



Press **F4** to enter the **SET DATE/TIME STYLE** menu.

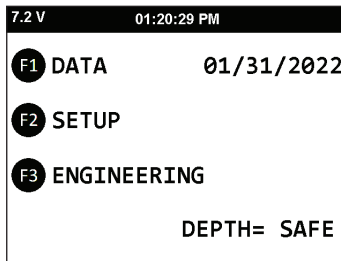


Press **F1** to change the highlighted **DATE** format.
Press **F2** to change the highlighted **TIME** format.
Press **F4** to **SAVE** the desired formats.

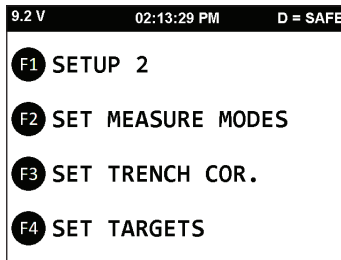


4.2.4 Units, Sound, and Timeouts Setup

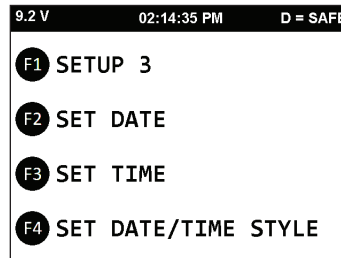
Press **F2** to enter the **SETUP** menu.



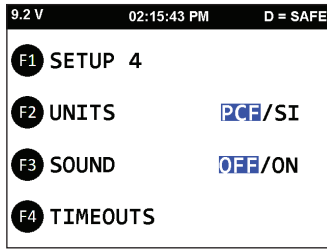
Press **F1** to enter the **SETUP 2** menu.



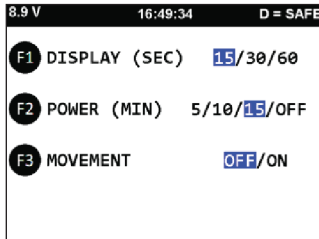
Press **F1** to enter the **SETUP 3** menu.



Press **F2** to change the highlighted **UNITS**.
 Press **F3** to change the beeper **SOUND**.
 Press **F4** to enter the power **TIMEOUTS** menu.



The **TIMEOUTS** menu as shown below:



This menu will allow the user to set different power saving settings.

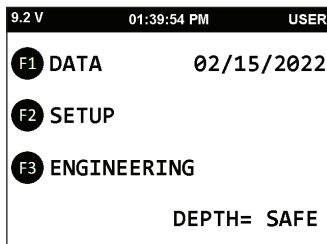
Pressing **F1** will toggle the **DISPLAY** timeouts for 15, 30, or 60 seconds. This will turn off the display to help conserve battery life. Pressing any key will turn the display back on where the user left off.

Pressing **F2** will toggle the gauge **POWER** timeouts for 5, 10, 15, or **OFF** minutes. This will help conserve battery life by powering down the Gauge to help conserve battery life.

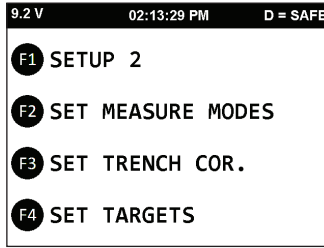
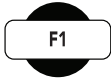
Pressing **F3** will toggle the gauge **MOVEMENT** detect function **ON** or **OFF**. When the gauge detects movement, it will automatically enter sleep mode. Pressing any key will wake up the gauge.

4.2.5 Backlight, Language and GPS

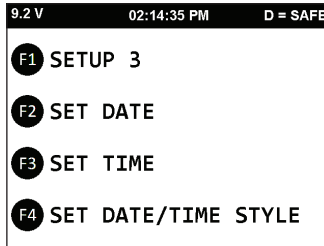
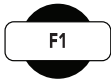
Press **F2** to enter the **SETUP** menu.



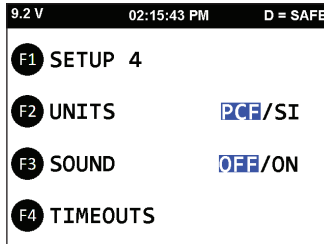
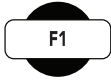
Press **F1** to enter the **SETUP 2** menu.



Press **F1** to enter the **SETUP 3** menu.



Press **F1** to enter the **SETUP 4** menu.



Shown below is the **SETUP 4** menu.



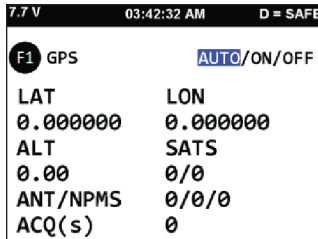
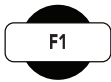
Press **F1** to change the **BACKLIGHT** function.
Press **F2** to change the **QR CODE** display menu.
Press **F3** to change **LANGUAGE** options.
Press **F4** to enter the **GPS** menu.

The backlight function can be changed from toggle to always on. In **TGL** mode the **BACKLIGHT** key will turn the backlight on and off. In **ON** mode the **BACKLIGHT** key will change the backlight from off to 5 different brightness levels. **NOTE:** Leaving the backlight always on will greatly reduce the life of the batteries.

The **QR FIRST** function will change the order of the measurement results screens. It will either display the **QR** code in the first or last screen depending on the setting used.

The **LANGUAGE** menu will allow the user to change the gauge language to **ENGLISH, SPANISH, or FRENCH.**

Press **F4** to enter the **GPS** menu.

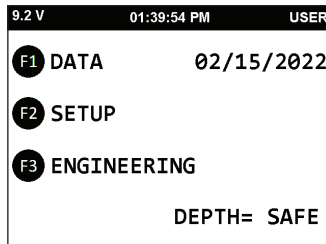
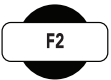


Pressing **F1** will change the highlighted mode **AUTO/ON/OFF**.

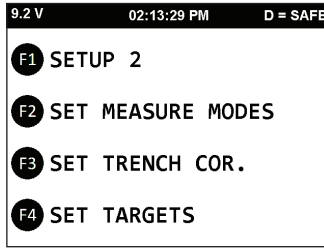
In **AUTO** mode the **GPS** will turn on and off when it necessary to help conserve battery life. **NOTE:** Independently of which power mode the **GPS** is set to. When entering the **GPS** menu, the **GPS** module will automatically turn on and then resume the setting it was set to after exiting from the menu.

4.2.6 Measurement Modes Setup

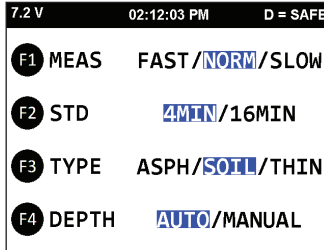
Press **F2** to enter the **SETUP** menu.



Press **F2** to enter the **SET MEASURE MODES** menu.



Shown below is the **MEASURE MODES** menu. Typically, **NORM**, **4 MIN**, **SOIL**, **AUTO** values will be highlighted.



Press **F1** to toggle the highlighted time **MEASUREMENT** modes.
Press **F2** to toggle the highlighted time **STANDARDIZATION** modes.
Press **F3** to toggle the highlighted material **TYPE** modes.
Press **F4** to toggle the highlighted index rod **DEPTH** modes.

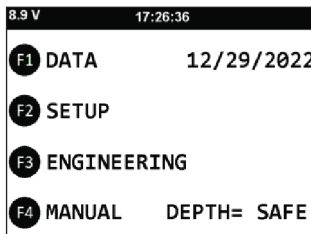
The measurement time settings are as follows (**FAST** = 0.25 min / **NORM** = 1.0 min / **SLOW** = 4.0 min).

The standardization time settings are as follows (**4 MIN** = Standard / **16 MIN** = Statistical).

The material type settings are as follows (**ASPH** = ASPHALT / **SOIL** = SOIL / **THIN** = ASPHALT THIN LAYER).

The index rod **DEPTH** settings are as follows (**AUTO** = Auto Detection / **MANUAL** = Manual Detection).

When the gauge depth is set to manual mode. “**F4 MANUAL**” will appear in the main menu screen as shown:



F4 = INCREASE DEPTH

F4 + **MAIN MENU** = DECREASE DEPTH

Press **F4** to **INCREASE** the desired index rod depth.

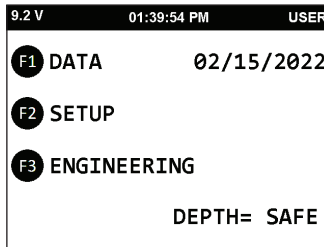
Press **F4** + **MAIN MENU** simultaneously to **DECREASE** the depth.

4.2.7 Trench Correction Setup

Please refer to section 3.7.2.4 SOIL Measurements in Trenches.

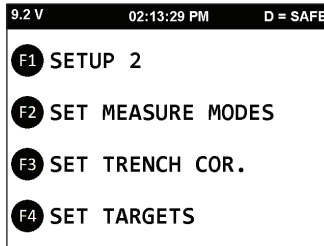
Press **F2** to enter the **SETUP** menu.

F2



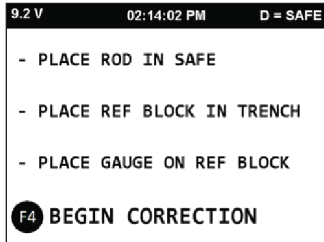
Press **F3** to enter the **SET TRENCH CORRECTION** menu.

F3



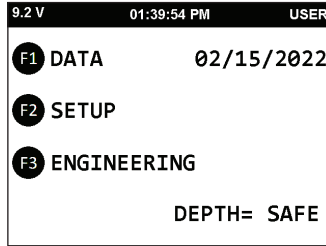
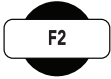
Press **F4** to start the **TRENCH CORRECTION**.

F4

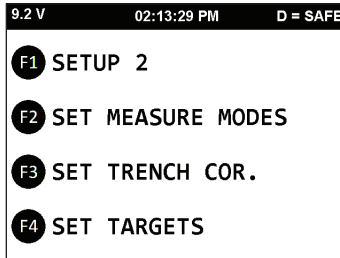


4.2.8 Targets Setup

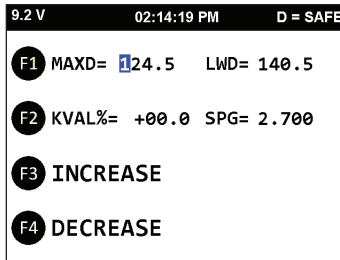
Press **F2** to enter the **SETUP** menu.



Press **F3** to enter the **SET TARGETS** menu.



The **TARGETS** menu as shown below:



Press **F1** to move the highlighted field for **MAXD** and **LWD**.
Press **F2** to move the highlighted field for **KVAL%** and **SPG**.
Press **F3** to **INCREASE** the value in the highlighted field.
Press **F4** to **DECREASE** the value in the highlighted field.

See section 3.3 **Entry of Pre-Test Data**.

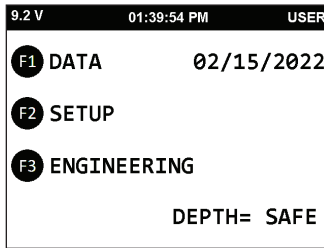
4.3 Engineering Menus

4.3.1 Calibration

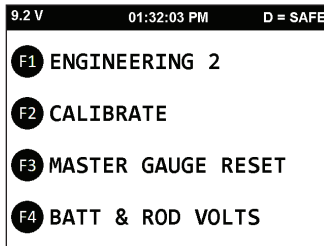
4.3.1.1 Field Calibration

As with water content, nuclear Gauges can have density errors due to the chemical composition of material, but they are far less than those encountered in moisture measurements. Generally, very few materials other than industrial waste used as aggregates or soils with high iron content will require adjustment. Most of the time, no corrections are required in the direct transmission mode unless there are original calibration errors. In the backscatter mode, the surface roughness or surface air voids may require some small correction. Again, original calibration errors account for a large percentage of these errors. The Gauge has a means of altering the factory calibration by a + / - percent value. There are nine sets (CAL1 through CAL9) available, and each set contains a separate adjustment value for backscatter and direct transmission densities.

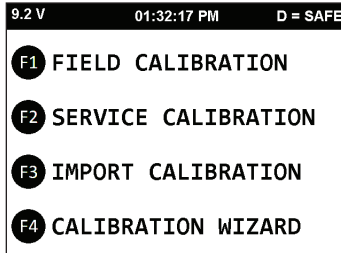
Press **F3** to enter the **ENGINEERING** menu.



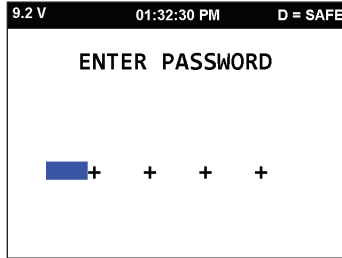
Press **F2** to enter the **CALIBRATE** menu.



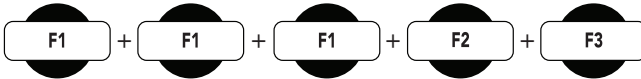
Press **F1** to enter the **FIELD CALIBRATION** menu.



Next the **PASSWORD** screen will display as shown:



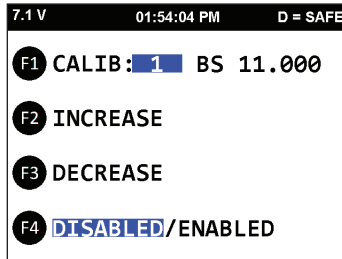
FIELD CALIBRATION PASSWORD



Press **F1+F1+F1+F2+F3** in sequence to enter the password.

NOTE: Once the correct password has been entered the menu will remain unlocked until the Gauge is powered off.

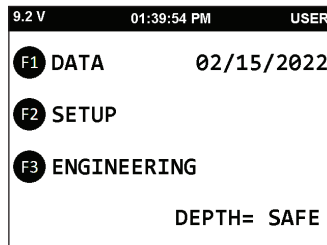
The following screen will display once the correct password has been entered.



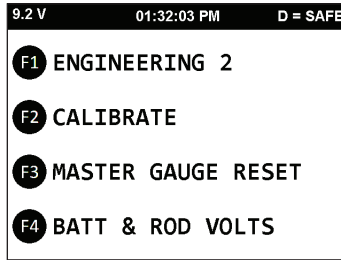
Press **F1** to move the highlight field to adjust the values.
Press **F2** to **INCREASE** the highlighted field value.
Press **F3** to **DECREASE** the highlighted field value.
Press **F4** to **DISABLE** or **ENABLE** the field calibration.

4.3.1.2 Service Calibration

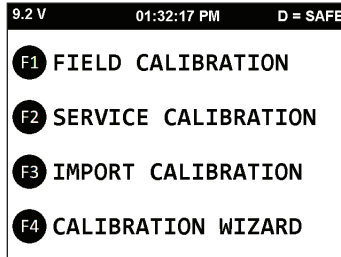
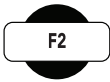
Press **F3** to enter the **ENGINEERING** menu.



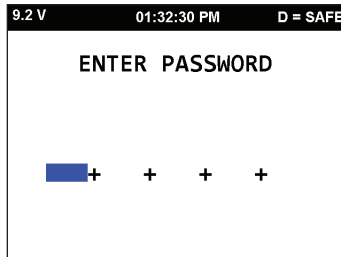
Press **F2** to enter the **CALIBRATE** menu.



Press **F2** to enter the **SERVICE CALIBRATION** menu.



Next the **PASSWORD** screen will display as shown:



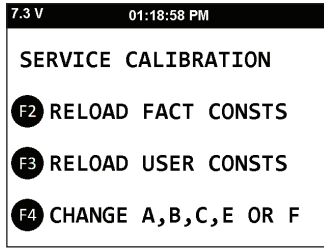
SERVICE CALIBRATION PASSWORD



Press **F2+F2+F2+F3+F4** in sequence to enter the password.

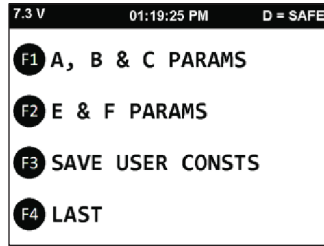
NOTE: Once the correct password has been entered the menu will remain unlocked until the Gauge is powered off.

The following screen will display once the correct password has been entered.

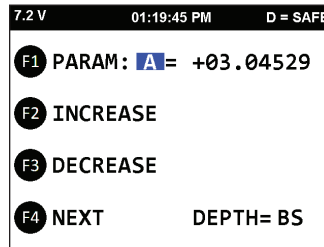
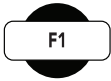


Press **F2** to Reload the **FACTORY** Constants.
 Press **F3** to Reload the **USER** Constants.
 Press **F4** to **CHANGE** the **A, B, C, E** and **F** parameters.

Pressing **F4** will display the screen as shown:

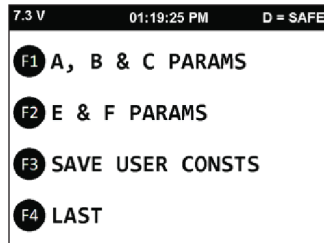


Press **F1** to edit the **A, B** and **C** PARAMETERS.

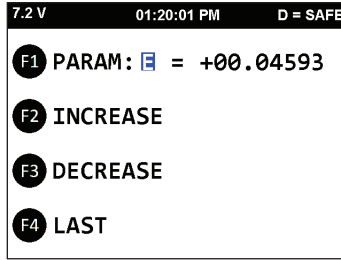
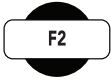


Press **F1** to move the highlighted field to be edited.
 Press **F2** to **INCREASE** the highlighted field.
 Press **F3** to **DECREASE** the highlighted field.
 Press **F4** to Advance to the **NEXT DEPTH**.

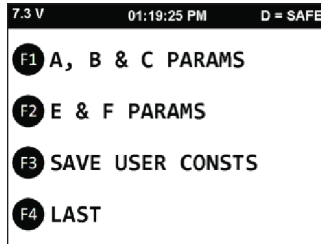
Once all the parameters have been changed press **MAIN MENU** to move back one menu as shown below:



Press **F2** to edit the E and F PARAMETERS.



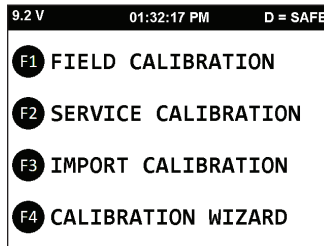
Press **F1** to move the highlighted field to be edited.
Press **F2** to **INCREASE** the highlighted field.
Press **F3** to **DECREASE** the highlighted field.
Press **F4** to move to the **LAST** screen or back one menu.



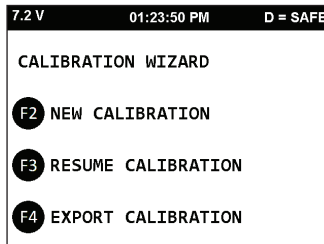
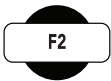
Press **F3** to **SAVE** the **USER CONSTANTS**.
Press **F4** to move to the **LAST** screen or back one menu.

4.3.1.3 Calibration Wizard

From the Calibration Menu Press **F4** to enter the **CALIBRATION WIZARD** menu as shown below:



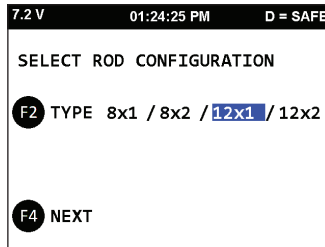
Press **F2** to enter the **NEW CALIBRATION** menu.



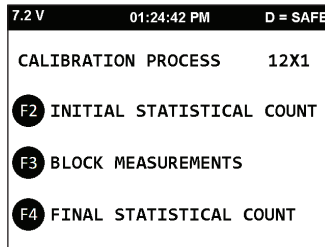
Press **F3** to **ERASE** and **START NEW** calibration.



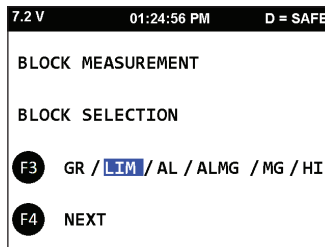
Press **F2** to move the highlighted field to the Gauge **TYPE**.
Press **F4** to move to the **NEXT** screen.



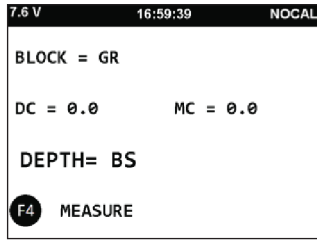
Press **F2** to enter the **INITIAL STATISTICAL COUNTS** menu.
Press **F3** to enter **BLOCK MEASUREMENTS** menu.
Press **F4** to enter the **FINAL STATISTICAL COUNTS** menu.



Press **F3** to move the highlighted field to the correct calibration block.
Press **F4** to enter the **NEXT** screen.



Press **F4** to **MEASURE** the Density and Moisture Counts.

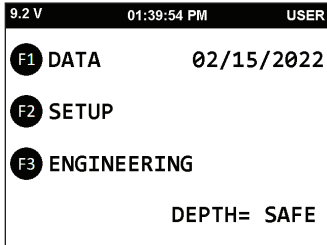


4.3.2 Reset Master Gauge

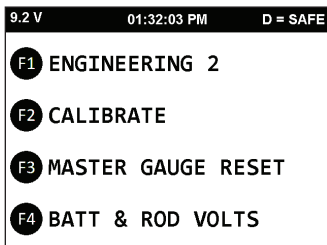
This procedure will completely clear everything from Gauge memory (other than calibration adjustments) and reload the data from the factory calibration.

It is not necessary to run this procedure except following a Gauge calibration.

Press **F3** to enter the **ENGINEERING** menu.



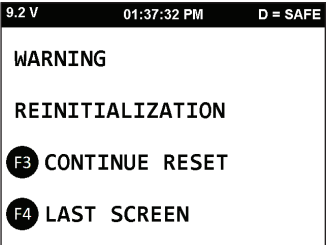
Press **F3** to enter the **MASTER GAUGE RESET** menu.



Press **F3** to **CONTINUE RESET** of the Gauge.

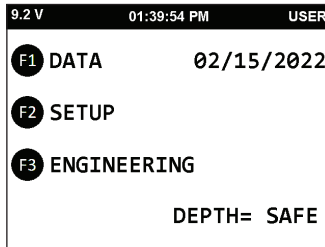
Press **F4** to return to the previous menu.

The display will return to the Main menu after the Master Gauge Reset has been performed.

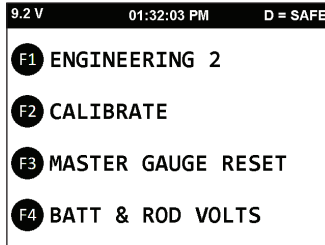


4.3.3 Battery & Rod Voltage Information

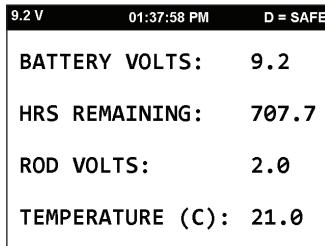
Press **F3** to enter the **ENGINEERING** menu.



Press **F4** to enter the **BATTERY** and **ROD VOLTS** menu.

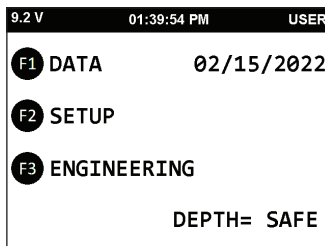


To exit the status screen, press the **MAIN MENU** key.

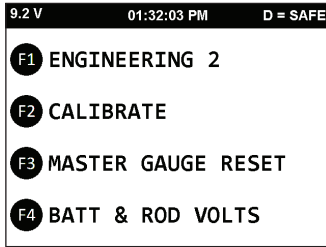
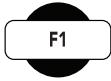


4.3.4 Manufactures Info and System Log

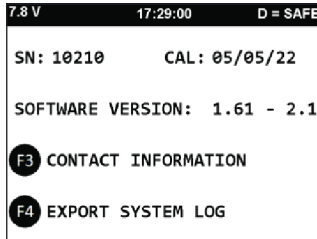
Press **F3** to enter the **ENGINEERING** menu.



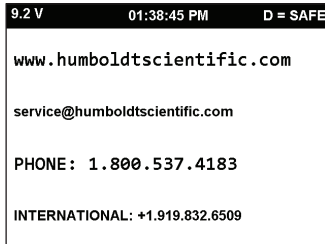
Press **F1** to enter the **ENGINEERING 2** menu.



Press **F1** for **MANUFACTURES INFO**.
Press **F3** to view **CONTACT INFORMATION**.
Press **F4** to **EXPORT SYSTEM LOG**.

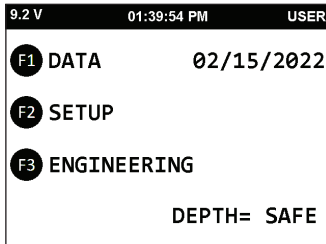


Contact information screen shown below:

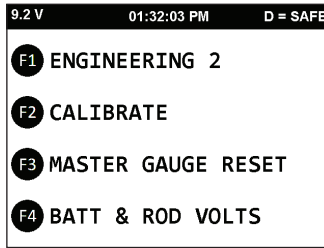
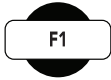


4.3.5 Gauge Firmware Update

Press **F3** to enter the **ENGINEERING** menu.



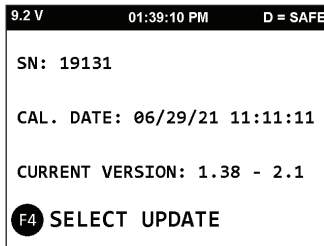
Press **F1** to enter the **ENGINEERING 2** menu.



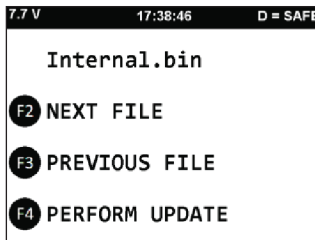
Press **F2** to enter the **UPDATE** menu.



Press **F4** to enter the **UPDATE SELECT** menu.



Press **F2** to advance to the **NEXT** file.
Press **F3** to advance to the **PREVIOUS** file.
Press **F4** to the **PERFORM UPDATE**.



After the correct update file has been selected, the Gauge will automatically perform the update and reboot when finished.

The update file is available on the Humboldt Scientific website. Under the Support Tab/Software/Firmware Downloads.

5 Preventive Maintenance

This equipment was designed for severe service and is a rugged instrument. If properly maintained it will require very little service other than routine maintenance.

5.1 Storage Environment

The instrument was designed to operate over an ambient temperature range of -10 to 70 °C. The storage temperature of the most critical components is -55 to 85 °C. There is not a likely chance that this range will ever be exceeded but storing it at room temperature will greatly extend its service life. The recommended range is 10 to 35 °C (50 to 95 °F).

The most damaging environment to electronic instruments is humidity. While it is possible to hermetically seal the instrument case, the cost would be prohibitive. It does have gaskets to seal out water from rain but the case must "breathe" and consequently water vapor moves in and out. If the combination of humidity and temperature causes condensation it will ultimately cause failure.

The interior parts are all non-corrosive or have protective coatings applied to slow down this process. The user can prevent condensation by limiting storage to a temperature range and humidity where condensation cannot occur and if it is likely remove the front panel during storage to allow moisture to evaporate and escape rather than be trapped inside. If it is used during a rain or exposed to surface water, it should be dried off before being put away.

5.2 Exterior Cleaning

The Gauge is going to get soiled during use. While this causes no harm, removing loose material at the end of each working day will prolong the cosmetic appearance.

Occasionally it would help if the exterior were cleaned with an industrial grade detergent and water. Heavy scrubbing may damage the finish on labels but will not harm the other materials.

The Source Rod and Index Rod may be sprayed with silicon oil and the excess wiped off with a cloth. The Source Rod is 440C stainless steel and while no pitting can occur, surface rust may form initially due to iron molecules brought to the surface by heat-treating. Light rubbing with an abrasive will remove it and after several times, it will no longer occur. Cleaning the top seal around the Source Rod will aid in preventing soil from working into the bearing, which is located below the seal.

5.3 Sliding Shield Cavity

A Sliding Shield of tungsten covers the gamma source when it is retracted to the "SAFE" condition. After prolonged use, the small amount of soil carried into the cavity with each retraction will accumulate in this cavity. If not periodically cleaned, the abrasion from the soil will increase the force

required to push the rod out and could cause jamming of the shield which will result in faulty STANDARD COUNT repeatability. Ultimately the soil will damage the seals between the cavity and the bearing.

The bottom plate, which contains a scraper ring to remove soil from the rod when it is retracted, can be removed by using a hex key to take out the two screws. Lay the Gauge on its side or end with the bottom pointed away from personnel and the rod in the "SAFE" position to prevent exposure from the source. Remove the screws and pull the plate away from the base. The sliding shield is held in place by a spring. Be careful not to let the spring fly off when removing the shield.

Clean the parts with a damp cloth and clean the cavity with a stiff brush. Finally, spray the parts and cavity with dry silicon spray.

The cavity and bottom plate are impregnated with Teflon and do not require extensive lubrication. If excessive wear has occurred to the bottom plate and scraper ring, they may need to be replaced.

Push the spring into the hole in the Sliding Shield and replace it in the cavity with the sloping side towards source and the spring compressed against the end of the cavity. If the sliding shield does not fully close it may be necessary to stretch / replace the spring. Replace the plate and screws being certain that they are tight and the heads of the screws do not extend above the surface of the plate.

5.4 Performing a Wipe Test

Regulations require that sealed capsules of radioactive materials be tested every six months to assure that they are not leaking. This is to prevent contamination of personnel and other equipment. Absorption of radioactive material into the body is the most severe accident that can occur in use of this equipment and there is little that can be done to remove it. Prevention of the absorption is the only solution.

The materials to perform this test have been supplied with the Gauge in kit (200177) and additional materials may be obtained from Humboldt Scientific, Inc. or other vendors of these kits. Ethanol (ethyl alcohol) at 95% purity may be obtained from a local beverage store under the trade name "Everclear". It is preferred but water may be used.

Since the user does not have access to the actual surface of the capsule, the regulations allow the wipe to be made on a surface that is likely to be contaminated by a leaking capsule. There are TWO sources in this Gauge. The gamma source is mounted in the source rod and the most accessible location to wipe is the hole in the case through which the rod extends in normal use. The neutron source is mounted in a cylindrical holder inside the case just behind of the main circuit board.

Most processors of these wipes allow both of these sources to be wiped with the same filter paper since they are able to determine from which source any contamination came. First fill out the form including the Gauge model and serial number, the type of radioactive material (Cs-137 and

Am- 241:Be) and the Gauge serial number (some kits also list the sources serial numbers). Include the owner's name and the address to which the form is to be returned.

Wet the filter paper with the solvent. Remove the front panel and locate the label around the Am-241:Be source holder. Using the tongs, wipe the threads of the allen screw at the top of the holder with the wetted paper. Lay the Gauge on its side with the base away from personnel so that the case provides a shield. Using the tongs to hold the paper, wipe the rim of the hole thoroughly with the wet paper. After wiping a source, do not touch the paper with fingers. Treat it as potentially radioactive material. Place the Gauge in the upright position. Place the filter paper in the plastic envelope and seal it.

Place the plastic envelope and the properly completed form in another envelope and mail it to the processor. The owner and authorities will be notified if the testing indicates a removable activity in excess of 5 nCi (0.005 uCi) which is the legal maximum allowable. An activity in excess of 1.0 nCi will likely result in a request to re-wipe the sources.

5.5 Statistical Stability Test

This test is a simple method of testing the short-term stability of the detectors and electronic counting circuits. The basis for it is explained in section 7.3 covering radiation statistics.

Radioactive decay is a binary process (an atom decays or it does not). The average rate of decay determines the half life (the time for half of the material to disintegrate) of the material. For Cs 137 this is 30.17 years and for Am 241: Be, it is 433 years. The decrease in the average rate of decay for Cs 137 is 2.3% per year and for Am 241: Be is 0.16% per year. Calibrating the Gauge in forms of a ratio eliminates the effect of this change on the measurement.

The short-term fluctuation of binary decay is predictable. The predicted standard deviation is the square root of the average count rate (m):

$$\sigma = \sqrt{m}$$

The Gauge electronics divide the actual events counted in a one-minute period by a factor of 16 before using the number, so the above expression is actually:

$$\sigma = \frac{\sqrt{m}}{4}$$

This equation can be used to predict the standard deviation of the count rate for a series of measurements. By taking a series of 16 measurements and computing the actual standard deviation, the value obtained can be compared as a ratio to the predicted value thus:

$$R = 4 \sqrt{\left[\frac{\sum (n - m)^2}{m (N-1)} \right]}$$

Where: σ = Standard deviation of count rate
 n = Individual measurement
 N = Number of measurement
 m = Mean of the measurement
 R = Statistical ratio

"STAT" automatically runs this series of measurements and displays the R values for the density and moisture channels. See section 3.2.

For: R > 0.6 and < 1.4 Good R
 < 0.5 or > 1.5 Bad
 Others— Try Again

6 FIELD SERVICE

The HS-5001EZ-2 is designed for reliability and field service is kept to a minimum. Little, if any, test equipment is required and the only tools necessary are:

Hex Key, 1/16 inch
 Hex Key, 1/8 inch
 Hex Key, 9/64 inch
 Hex Key, 3/16 inch
 Phillips Screwdriver, #1 x 4 inch

Your Radioactive Material License must specifically allow removal of the Source Rod if the rod bearings and seals are to be removed, cleaned or replaced.

6.1 Mechanical Disassembly / Assembly

6.1.1 Bottom Plate and Shield

The Bottom Plate Assembly (200666) is held in place by two Flat Head Hex Socket Screws (001010). Removing them will allow the plate to pull away and the Sliding Shield (200030) and Spring (000816) can be removed for cleaning. The Scraper Ring (000806) in the Plate (200665) can be replaced by removing the Retaining Ring (000811).

6.1.2 Source Rod

Other than replacing a set of bearings, it is not necessary to remove the Source Rod. A suitable shield must be available. **REQUIRES**

AUTHORIZATION FROM REGULATORY AGENCY ON USERS LICENSE.

Drop the Source Rod to the backscatter position. Loosen the two Hex Set-screw (001007) at the top and unscrew the Lift Cap (200667) and the

Auto Lift Bumper (200278) to allow complete removal of the Source Rod and handle. Hold the rod by the handle with the tip as far as possible from the body and store it in a shielded container with a minimum 25 mm (1 inch) lead wall or in one of the calibration standards at least 3 m (10 ft) from personnel work areas. The rod must not be left unattended and should be replaced in the Gauge shield as soon as practical.

6.1.3 Indexer and Latch

This may be accomplished without removing the source rod from the Gauge. Remove the Lift Cap as described in 6.1.2. Raise the handle off of the Index Rod and rotate it 90°: Push the rod back into the shield. Remove the two Hex Setscrew (001034) at the end cap of the handle and slide the complete latch assembly and Index Pin (200660) out the rear of the handle. These parts are lubricated by the Teflon coating.

6.1.4 Index Rod

The Index Rod may be removed without removing the Source Rod. Remove the Lift Cap as described in 6.1.2, lift the handle off the Index Rod and rotate it out of the way. MAY REQUIRE FACTORY RE-CALIBRATION.

Loosen the Index Lock Nut (200052) and unscrew the Index Rod (200668, 669, 670 or 671) from the post. When replacing the Index Rod. Latch the handle firmly in the backscatter position and screw the Index Rod until the tip of the Source Rod is flush to 0.05 mm (0.002 inch) recessed within the bottom of the Gauge. The rod must not protrude or backscatter measurements in the field could be in error. Tighten the Index Lock Nut (200052).

6.1.5 Top Cover

First remove the Processor (scaler) Module (200682) by releasing the four Thumbscrews (001013). Lift the panel out and disconnect the Module Cable (200573) from the base frame assembly.

Remove the six Socket Head Cap Screws (001008) and Washers (001030) around the edge of the cover. The cover can be totally removed from the Gauge by placing the handle partially between the backscatter and safe positions and working the cover over it. It will be easier if the Post Grommet (200109) is removed from the hole. If worn or damaged, the Bottom Gasket (200149) or Panel Gasket (200351) should be replaced.

6.1.6 Top Post and Seals

The seals and wipers will wear due to soil abrasion and soil working into them as the Source Rod is moved up and down. Keeping the bottom cavity clean and lightly lubricating the Source Rod with silicon grease will help prolong their life.

Caution: the owner's license must allow Source Rod removal before this service may be performed. With the Source Rod removed and safely stored as covered in 6.1.2 and the Top Cover removed: Remove the four Socket Head Cap Screws (001009) and Lock Washers (001031) from around the Post. The Post may be lifted up over the tungsten bio shield.

The Wiper Plate (200031) and Wiper Ring (000803) may be removed from the inside of the post. When replacing them, the wiper goes into the top of the plate such that it cleans the Source Rod as it moves in an upward direction.

The Top Wiper Cap (200032) may be removed from the Post by removing the two Hex Socket Screws (001007) from the side of the Post. Pry up lightly on the Cap. The Wiper Ring (000803) in the Cap may be replaced by carefully prying it out of the top.

The two Bearing Seals (000805) may be removed by carefully prying them out of the center hole. The seals will be destroyed but be careful not to damage the Source Rod Bearing (200136). When replacing the seals, they must be pushed or lightly tapped in place with a wood or soft metal dowel to prevent damage. The bearing has recesses for soil to accumulate to prevent binding. Clean the bearing with a solvent and lubricate with silicon grease. Lightly coat all of the seals and wipers with the same grease before reassembling. Reassemble in reverse order.

6.1.7 Base Module

There are high voltage capacitors on the circuit board, which may be charged to 900 volts. The current available is low but injury may occur due to the surprise of receiving a severe shock. Discharge them by firstly sliding the circuit breaker at the top of the batteries pack to the off position and secondly pressing and holding the push-button switch at the top of the circuit board for about one second.

Remove the Top Cover as described in 6.1.5. Remove the seven Socket Head Cap Screws (001008) and Lock Washers (001029) around the edge of the module. Carefully lift the Base Module up out of the Gauge Base. The detectors may be replaced if necessary and the parts reassembled.

6.2 Battery Replacement

The batteries in this Gauge will last a very long time if the Gauge is not stored at a high temperature. The expected service life is 1400 hours. Replacement will be required within one to two weeks after the "LO BAT" symbol appears in the Display while in use.

Replacement batteries should be high quality alkaline AA size cells such as those made by Mallory (DURACELL). Do not replace with manganese zinc cells except in an emergency for a short period of time. They will not last as long and leakage may cause damage to the inside of the Gauge. Remove the screws and lift battery cover. Slip the batteries out of the holders. Replace the cells with the same orientation showing in the battery holders.

6.3 Electronic Modules Adjustment / Replacement

In order to improve reliability and maintain ease of service, the HS-5001EZ electronics are divided into four modules, which may be individually replaced. Two of them have adjustments, which may need to be set.

6.3.1 Processor Module (200682)

This Front Panel Module contains two counting systems, a programmed microprocessor and a display. Field service is impractical other than replacement. It is easily removed by means of four thumbscrews located in the corners. The cable is disconnected from the Base Plane Module by releasing the latches at each end of the connector. Note that the cable, when properly installed, has no twists in it, only a 180° turn.

The Factory or Authorized Service Facility may repair or replace the module. No re-calibration is necessary; however, the Gauge calibration is stored in a memory module that must stay with the same Gauge or re-calibration will be necessary.

6.3.2 Base Plane Board (200757)

This Board, into which all of the small modules are plugged, has no active components, only interconnects between other components. The probability of failure is very low except for physical damage. Should it become necessary to replace it, some soldering is required so either the entire Base Frame must be replaced, or returned, or the entire Gauge returned. No re- calibration is required.

For protection a circuit breaker is above the battery holders which will open up if the main power circuits become shorted. A red indicator is visible when the circuit breaker is closed and applying power to the board. The Base Board also has a push-button switch in the upper center of the board which is used to discharge the high voltage before servicing any of these circuits. This button should be pushed and held for about one second before removing or replacing the High Voltage, Density, or Moisture Modules.

The entire frame, including the detectors, is removed by means of the seven screws around the edge of the frame. Do not remove the screws, which attach the Board to the frame.

6.3.3 High Voltage Power Supply Module (200088.R2)

This module supplies a highly regulated 900 vdc to the Density and Moisture Amplifier modules and in turn to the detectors. From unit to unit, the voltage may vary ± 25 volts but once established, it is very stable.

This voltage can cause a severe shock and before any replacement is attempted, the discharge push-button switch located in the center of the base circuit board must be pushed and held for about one second.

The module is easily replaced by removing the screw located in the middle of the module. When plugging in another one, look and at the pins closely and orient the module pins to the circuit board sockets. If they are aligned the module can be inserted easily. Do not apply force as the pins may be bent or damaged.

The module is not repairable, and must be replaced if defective. The replacement does not affect calibration.

6.3.4 Density Amplifier Module (200087)

This module is used to condition varying amplitude pulses from the two gamma detectors to logic level pulses for the counter in the Processor Module.

There are two adjustments, which control the amplitude of the pulses from each of the detectors. They should be set, using an oscilloscope, to produce average 500 millivolt negative pulses at test point DTP on the base circuit board. This pulse height is not very critical and if the adjustments are set at mid range, and the STAT test indicates stability, the setting is acceptable without the availability of the oscilloscope.

The high voltage can cause a severe shock. Before any replacement is attempted, the discharge push-button switch located in the center of the base circuit board must be pushed and held for about one second. The module is easily replaced by removing the screw located in the middle of the module. When plugging in another one, look at the pins closely and orient the module pins to the circuit board sockets. If they are aligned, the module can be inserted easily. Do not apply force as the pins may be bent or damaged.

The module is not repairable, and must be replaced if defective.

6.3.5 Moisture Amplifier Module (200086)

This module is used to condition varying amplitude pulses from the thermal neutron detector to logic level pulses for the counter in the Front Panel Module.

There is one adjustment, which controls the amplitude of the pulses from the detector. It should be set, using an oscilloscope, to produce average 500 millivolt negative pulses at test point MTP on the base circuit board. This pulse height is not very critical and if the adjustment is set at mid range, and the STAT test indicates stability, the setting is acceptable without the availability of the oscilloscope.

The high voltage can cause a severe shock. Before any replacement is attempted, the discharge push-button switch located in the center of the base circuit board must be pushed and held for about one second. The module is easily replaced by removing the screw located in the middle of the module. When plugging in another one, look at the pins closely and orient the module pins to the circuit board sockets. If they are aligned the module can be inserted easily. Do not apply force as the pins may be bent or damaged.

The module is not repairable, and must be replaced if defective.

6.4 Detector Replacement

If total failure of a detector occurs or if adjustments to correct instability problems are not possible, then the detectors require replacement. The procedure is quite simple.

Remove the Base Frame Module as instructed in 6.1.7 after discharging the high voltage. The Gamma Detector(s) (200035) may be removed by sliding them out of the side of the module. When replacing the Gamma Detectors, note that a leaf spring is in contact with the shell and needs to be compressed when sliding in the replacement.

The Moisture Amplifier must be removed in order to slide the Neutron Detector (200026) out of the frame. Slide the new detector in place and carefully install the amplifier so the module pins and the detector connector engage. **NOTE:** any replacement of the detectors will requires re-calibration.

6.5 Parts List

This list includes all parts, which may be field replaced.

Tool Set	200112
Zippered Accessory Case	200175
Drill Rod	200130
Scraper Plate/Rod Guide	200127
Rod Extractor Tool	200145
Hammer	000176
Transit Case Assembly	
200681	
Reference Standard	200122
Gauge Padlock	000177
Instruction Manual, HS-5001EZ-2	200025
Radiation Safety Manual	200121
Radioactive Source Certificate	200173
Wipe Test Materials (Kit)	200177
Leak Test Certificates	200174
Filter Paper	000175
Plastic Bags	000178
Forceps	000181
Lift Cap	200667
Hex Socket SS Set Screw, 6 32 x 3/16 (2)	001061
Lift Bumper	200278
Index Rods	
8 X 1	200668
8 X 2	200669
12 X 1	200670
12 X 2	200671
Index Lock Nut	200052
Handle Assembly	200664
Gauge Handle	200661
Lift Handle	200662
End Cap	200663
Index Pin	200660
Cs Source Label	200091
Roll pin, 0.125 x 0.375	001020

Handle Repair Kit	200659
Top Cover Assembly	200170
Top Cover	200133
Post Grommet	200109
Bottom Gasket	200149
Panel Gasket	
200351	
Panel Nut, 8 32 (4)	200163
Washer, Internal Tooth ¼", SS (4)	001037
Radioactive Material Label	200134
Hex Socket Head SS Cap Screw, 8 32 x 1/2 (6)	001008
Flat SS Washer, #8 (6)	001030
Drive Screws #00	001023
Processor Module	201015
Front Panel Assembly	
Front Panel	201006
Captive Screw (4)	001013
Processor Circuit Board Assembly	
Display Board	201001
Processor Board	201002
EZ Module Cable	200573
Post Module Assembly	200031
Post Assembly	200154
Bearing Post	
200028	
Source Rod Bearing	200136
Top Wiper Cap	200032
Wiper Ring	000803
Hex Socket SS Set Screw, 6-32 x 3/16 (2)	001007
Seal 5/8" (2)	000805
Shield Insert	200156
Hex Socket Head SS Cap Screw, 1/4-20 x 1 (4)	001009
Lock Washer, SS Split Spring, 1/4 (4)	001031
Gauge Base (No internal Parts)	200027
Bio Shield	200029
Bottom Plate Assembly	200666
Bottom Plate	200665
Scraper Ring	
000806	
Retainer Ring	000811
Flat Head Hex Socket SS Screw, 8-32 x 1/2 (2)	001010
Sliding Shield	200030
Shield Spring, SS	000817
Am:Be Source Label	200092
Hex Socket SS Set Screw, 5/8 18 x ½	001032
Base Frame Assembly	
200201	
Hex Socket SS Cap Screw, 8 32 x 1/2 (7)	001008

Lock Washer, SS Internal Tooth, #8 (7)	001029
Base Circuit Board Assembly	200757
Phillips Head SS Screw, 6 32 x 1/2 (6)	001005
Lock Washer, SS Internal Tooth, #6 (6)	001006
High Voltage Power Supply Module	200088.R2
Phillips Head SS Screw, 6 32 x 1 1/4	001042
Lock Washer, SS internal Tooth, #6	001006
Density Amplifier Module	200087
Phillips Head SS Screw, 6 32 x 3/4	001004
Lock Washer, SS internal Tooth, #6	001006
Moisture Amplifier Module	200086
Phillips Head SS Screw, 6 32 x 3/4	001004
Lock Washer, SS internal Tooth, #6	001006
Ground Spring	200162
Phillips Head SS Screw, 4 40 x 1/4	001054
Lock Washer, SS Internal Tooth #4	001018
Detector, Gamma (2)	200035
Detector, Neutron	200026
Screw Set (5001)	200178
Gasket Set (5001)	200179
Seal and Wiper Set	200199
Silicon Grease, General Purpose	000174

6.6 Service Hints

No Power Check	Batteries and Circuit Breaker, Replace Processor Module
Not Counting Anything	Replace High Voltage Power Supply, Replace Processor Module
Not Counting Moisture	Check Pulse Voltage at MTP, Replace Moisture Amplifier Module, Replace Neutron Detector
Not Counting Density	Check Pulse Voltage at DTP, Replace Density Amplifier Module, Replace Gamma Detectors
Unstable Moisture	Check Pulse Voltage at MTP, Replace Moisture Amplifier Module, Replace Neutron Detector
Unstable Density	Check Pulse Voltage at DTP, Replace Density Amplifier Module, Replace Detector(s)
Density Counts Half	Replace Density Detector
Low Unstable Counts	Replace High Voltage Power Supply Module
Keys don't do Function	Replace Front Panel

6.7 Calibration

The Calibration of this instrument will be valid for a minimum of one year and probably much longer if reasonable care is taken to prevent the application of heavy shock loads to the Gauge base.

Users are advised to establish a location on a laboratory floor or other reference and measure this location on receipt of the equipment. Periodic measurement of this location will provide a means of verifying the calibration over a long period of time.

Any discrepancy in this measurement or suspected errors in field data will indicate the need for calibration. If the owner does not have facilities to perform the Calibration as covered previously then the equipment should be returned to an Authorized Service Facility or the factory.

7 Theory of Operation

This instrument uses two types of radiation to measure the density and moisture content of materials. The interaction between the radiation and the materials is very different but most of the electronics are compatible with the two functions. Both measurements are indirect in the sense that another parameter of the material is actually measured and the parameter then stated in terms of density and moisture.

The differences between the measured parameters and the desired density and moisture is typically called "composition" or "chemical" error since it does involve the chemical elements or molecules which form the materials.

7.1 Density Measurement by Gamma Radiation

Gamma radiation is a form of electromagnetic radiation similar to the radio frequencies that carry television signals and rays of visible light. The only difference is one of frequency. At the frequency of gamma radiation, materials exposed to it are ionized and this creates a hazard to living tissue. Gamma and X radiation's are identical and are only differentiated by their origin. X radiation is emitted when electrons change energy states and gamma is emitted from the nucleus when some types of radioactive decay occur. While one normally thinks of electromagnetic radiation as occurring in continuous waves, at higher frequencies it is more usual to analyze the effects in quanta or points of energy (photons) having zero rest mass.

An isotope of Cesium-137 with a half life of 30.17 years is used in this Gauge to produce gamma radiation. The isotope decays with the emission of a beta particle having a maximum energy of 1.176 MeV and an average of 0.195 MeV. The Cesium-137 is transformed into Barium-137m which has excess energy and decays with a half life of 2.5 minutes to a ground state with the emission of gamma having an energy of 0.662 MeV.

The nominal amount of Cesium-137 used is 10 mCi with a rate of decay at 3.7×10^9 disintegration per second. The efficiency of gamma production

is 85% so 3.2×10^8 photons are produced per second. The beta particles are absorbed by the capsule wall.

When gammas of this energy pass through materials, either of two interactions may occur. At the original energy of 0.662 MeV, the primary effect is collision with the loosely bound electrons of the material with a scattering (change in direction) and transfer of energy. As scattering continues and the energy decreases, photoelectric absorption occurs in which the gamma transfers all of its energy to a more tightly bound electron and the electron leaves the atom which may result in some X radiation.

As evident from the above, the interaction is with the electrons in a material and not the nucleus which contains most of the mass. Consequently the Gauge actually measures the electron density of the material which is only approximately related to the mass density. The relationship is the ratio of the Z (atomic number or number of electrons per atom) and A (atomic mass of the atom). The term Z/A is used frequently.

The process is further complicated by the probability that the interaction will or will not occur. Atoms are mostly voids so many gammas will simply pass through with no interaction.

The probability is a function of both the atomic number and the energy of the gamma and is different for scattering and photoelectric absorption. We will combine the two and call the resultant probability as the "mass attenuation coefficient" or u/p .

The classic equation for the attenuation of gamma passing through material is:

$$I = I_0 * e^{-L * \rho * u/p}$$

Where:

I = resulting intensity

I_0 = Initial intensity

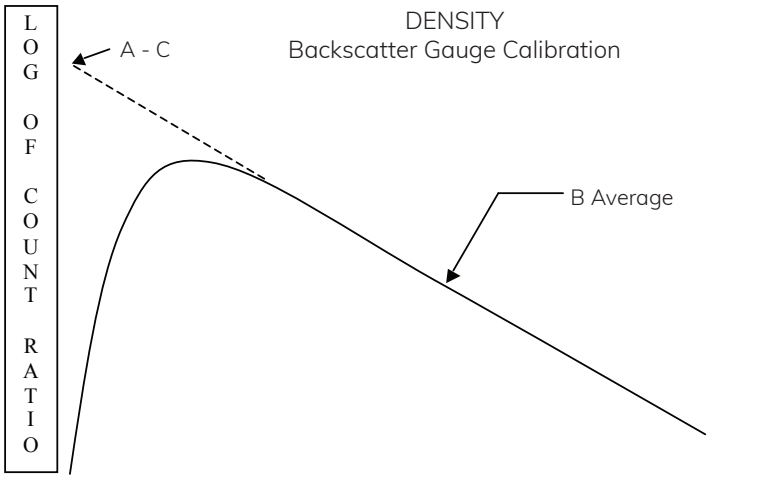
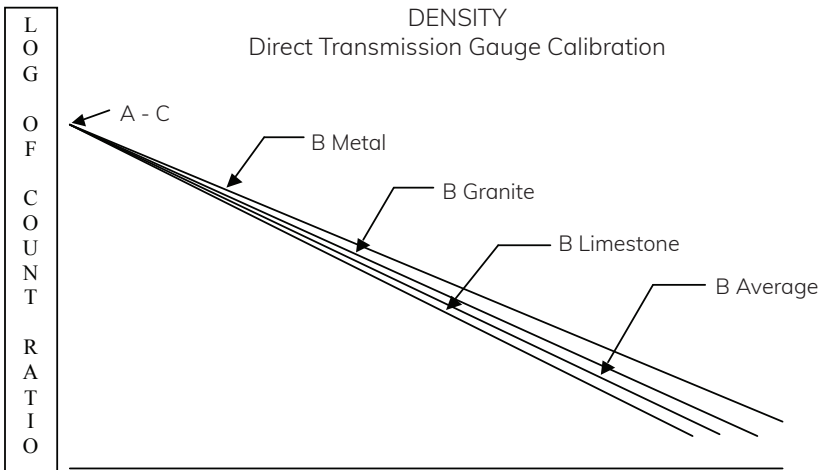
L = path length

ρ = density of material

u/p = attenuation coefficient

The table below indicates the relative percentage for the most predominant elements in the crust of the earth along with their values of Z/A and u/p .

Element	Percent	Z/A	$u/p(0.662 \text{ MeV})$
Oxygen	44.6	0.500	0.0806
Silicon	27.7	0.498	0.0805
Aluminum	8.1	0.482	0.0777
Iron	5.0	0.466	0.0762
Calcium	3.6	0.499	0.0809
Sodium	2.8	0.478	0.0772
Potassium	2.6	0.486	0.0787
Magnesium	2.1	0.498	0.0796
Hydrogen	-	0.992	0.1600



Fortunately the most common materials in the surface layers are oxygen, silicon and calcium in the form of oxides or carbonates. If this were not the case, Gamma Density Gauges would not be practical for use. These materials all have a μ/ρ between 0.0805 and 0.0809. Large amounts of hydrogen in surface water do require an adjustment in the measured density.

The equation indicated is not practical for use in a Gauge since the mass attenuation coefficient varies with energy which is changing as the gammas pass through materials and the detectors used are not linear with energy.

While many equations may be used to fit the data, the most common is:

$$CR = A * e^{-BD} - C$$

Where:

CR = Count rate or Ratio at the detectors

D = Density of the material

A,B,C = Constants

Geiger Mueller detectors are used in the system along with a gamma filter to select the desired energy spectrum. The filter limits the low energy response and the detector design limits the upper energy, which can be detected. The available energy at the filter is a function of the initial energy of the gamma radiation from the source and the path length through the material.

The count rate at the detectors is ratioed to a standard set of conditions in order to eliminate drift of the system and the effect of aging of the radioactive material over long periods of time.

This table lists the mass attenuation coefficients for suggested calibration materials covering the possible range of photon energy. The values are calculated from data included in "Gamma Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV" published by NIST.

**Mass Attenuation Coefficients (cm²/g)
GAMMA ENERGY(MeV)**

Material	0.10	0.15	0.20	0.30	0.40	0.50	0.60
Magnesium	0.1610	0.1360	0.1220	0.1060	0.0944	0.0861	0.0796
Magn./Alum	0.1620	0.1350	0.1210	0.1040	0.0931	0.0849	0.0784
Aluminum	0.1620	0.1340	0.1200	0.1030	0.0922	0.0841	0.0777
Limestone	0.1920	0.1460	0.1280	0.1080	0.0960	0.0874	0.0808
Granite	0.1640	0.1370	0.1240	0.1070	0.0950	0.0867	0.0802
Lime/Gran.	0.1780	0.1415	0.1260	0.1075	0.0955	0.0870	0.0805
Water	0.1680	0.1490	0.1360	0.1180	0.1060	0.0967	0.0895

After using this data to correct the metallic materials, the experimental count rates will give an equation, which is still not applicable for construction materials. Assuming that most construction materials will have a composition between limestone and granite, the metallic values of A and C can be used to calculate a value of B which applies to these materials or other values of B can be determined for any material.

Experimental data must be used and not the values from the above table. The initial gamma energy is known to be 0.662 MeV but the average energy for the interactions would be impossible to determine. Gamma filters are used with the detectors to limit the lower energy in order to reduce the errors due to chemical composition.

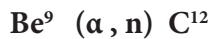
Using energy discriminating detectors, the lowest possible chemical error for limestone and granite is $\pm 0.4\%$. With Geiger Mueller detectors and mechanical filters, the practical limits are about 2% for backscatter modes and 1.5% for direct transmission.

The direct transmission mode involves placing the source and detectors across the material (opposite sides) so that the gamma path is directly through the material. This is the most accurate method due to the higher average energy and the method produces true average densities.

The backscatter method involves placing the source and detectors on the same surface of the material. The gamma must be deflected back prior to measuring the attenuation by the material. As a result, the average energy is lower and the method does not produce a true average density since a larger portion of the gammas pass through the materials closest to the surface and less at deeper depths.

7.2 Moisture Measurement by Neutron Radiation

Neutron radiation is in the form of a particle having no electrical charge. The particle is emitted from the nucleus of an atom usually as the result of having absorbed a very high-energy gamma or an alpha particle. While very rare, a neutron may result from spontaneous fission. For industrial use, isotopic sources are available which consist of alpha radiation combined with beryllium metal. The reaction is:



When the beryllium nucleus reacts with the alpha particle it becomes an isotope of carbon. The C12 is left at an excess energy state and yields a 1 to 10 MeV neutron when it goes to the ground state.

In the 5001, Americium 241 is used as the source of alpha. The 40 mCi source yields an average of 9×10^4 neutrons per second. The Americium-241 also yields low energy gammas, which are shielded out in the source holder.

The neutron interaction with matter is relatively complex. Having no charge, it passes through atoms quite readily and unless it collides with the nucleus of an atom little or no energy is lost. Only when the collision involves a Low Mass nucleus such as hydrogen is there a significant loss of the neutron energy and that loss is dependent on the angle of the collision.

The neutrons from an Am 241: be source starts with an average energy of 4.5 MeV. With each collision some energy is lost until the neutron reaches energy of about 0.025 eV. This value is called thermal since it equals the velocity of surrounding materials at room temperature which is 2200 m/s (7300 ft/s). The neutron may decay with a half life of 11 minutes or, at thermal energy, may be captured by another atom. The elements in the earth's crust, which may either thermalize or capture thermal neutrons, are listed below.

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Element	Percent	Collisions	Absorption
Hydrogen		19	0.33
Boron	<0.1	109	759.00
Carbon	<0.1	121	<0.01
Oxygen	44.6	159	<0.01
Sodium	2.8	225	0.53
Magnesium	2.1	237	0.06
Aluminum	8.1	263	0.23
Silicon	27.7	273	0.16
Chlorine	<0.1	343	33.00
Potassium	2.6	378	2.10
Calcium	3.6	387	0.43
Manganese	<0.1	529	13.30
Iron	5.0	537	2.53
Cadmium	<0.1	1075	2390.00
Lead	<0.1	1976	0.17

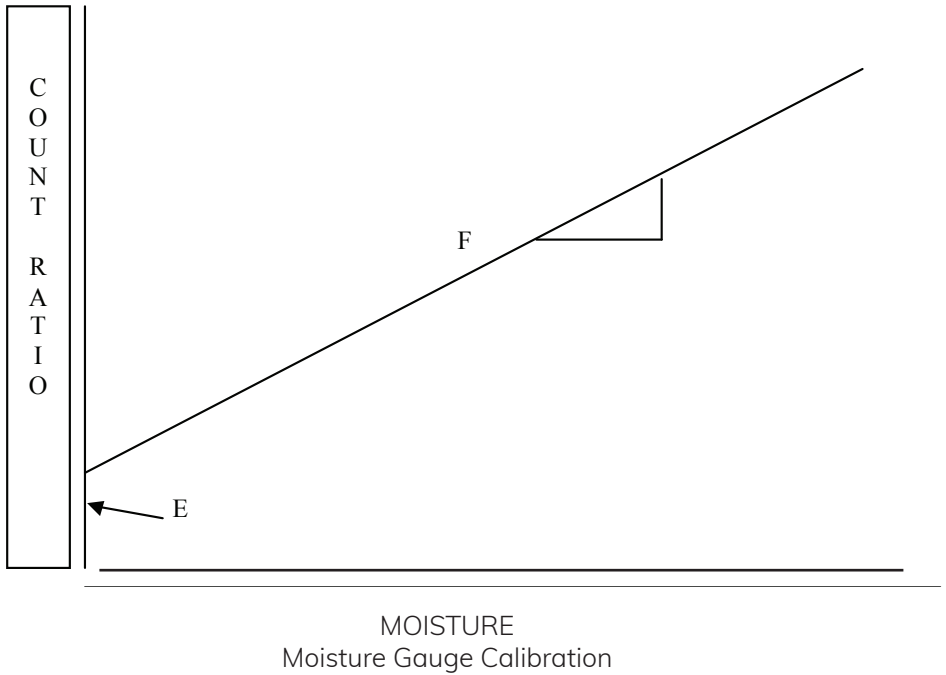
Note that the number of collisions required to produce thermal neutron increase rapidly above hydrogen and the only other significant elements that are present, oxygen and silicon require a much larger number of collisions. Oxygen of which there is a large amount is usually uniformly distributed with all elements in the form of oxides, including water.

For this reason, if a thermal neutron exists there is a very good probability that it was produced by collision with hydrogen. While most hydrogen in construction materials is in water, there may be hydrated minerals that contain large amounts of hydrogen and the error must be corrected.

The Absorption column lists the cross section (probability) of the material capturing a thermal neutron. Outside of some rare elements such as cadmium, only boron and to a lesser degree chlorine, manganese and iron have a cross section a great deal higher than hydrogen.

These elements seldom cause errors with the exception of a few areas, which have large amounts of boron, coastal areas, which may have significant sodium chloride in the soil, and a few locations where iron oxide may be present in large amounts.

Helium-3 is an isotope that has a very large capture cross-section for thermal neutrons and the detector in the 5001 is filled with this gas at a high pressure so that it is very efficient. If the source and detector are mounted very close together, the relationship between detected thermal neutrons and hydrogen (water) is linear over the normal range of soil moisture.



The count rate is ratioed to a standard count and a suitable equation is:

$$CR = E + F * M$$

Where:

CR = Count Ratio

M = Moisture content

E = CR at zero moisture content

F = Slope of the function

In order to determine the values of E and F, two moisture standards are required. One may be zero since it is easy to obtain and the other must have a known amount of water or contain hydrogen, which can be related to water.

The moisture measurement is sometimes called backscatter but once a neutron has been thermalized by multiple collisions with hydrogen, it obeys gas diffusion laws and drifts off in any direction. Some arrive at the detector and get counted.

7.3 Radiation Statistics

Radioactive decay is a binary process, any given atom may decay or it may not. For large quantities of atoms a Poisson distribution very accurately describes the process. This distribution has a standard deviation s , which is equal to the square root of the mean rate of decay. The predicted precession of the count rate is defined as \pm one standard deviation.

The mean of a sample is:

$$m = \frac{\sum n}{N}$$

Where N number of samples:

The predicted precision of the sample is:

$$\sigma(n) = \sqrt{m}$$

The one standard deviation spread of a single sample is:

$$n = n \pm \sqrt{n}$$

From these equations it is evident that the predicted precision of the Gauge is directly related to the square root of the number of detector counts accumulated during a measurement. Further, the precision can be improved either by counting a longer time period or by averaging the count rate for a number of measurements and this improvement is the square root of the number of measurements made.

While the precision of the Gauge in count rate shows the trend, what is of interest is the precession of the density and moisture measurement. In order to obtain this information, it is necessary to know the change in the measured parameter in terms of a change in count rate. This is the slope of the calibration equation.

$$CR = A * e^{-BD} - C$$

Or

$$n = DS * A * e^{-BD} - C$$

Then the differential is:

$$S = \frac{dn}{dD} * A * e^{-BD} - C$$

Which is the slope in terms of counts per minute per unit density. Combining this equation and the equation for precision and accounting for the pre scale value of 16 yields:

$$DP = \frac{\left(\sqrt{(DS * A * e^{-BD} - C)}\right)}{4DS * A * B * e^{-BD}}$$

Where:

- DP= Density precision at density D
- D= Density
- DS = Density standard count
- A, B, C = Calibration constants
- S = Slope

This is for one standard deviation, a 68% confidence factor.

Applying the same procedure to the moisture equation results in an equation for the moisture precision:

$$MP = \frac{\left(\sqrt{(MS * (E + F * M))}\right)}{4MS * F}$$

Where:

- MP = Moisture precision
- M = Moisture
- MS = Moisture standard count
- E, F = Calibration constants

Both of the above previsions are stated for the one minute (NORM) measurement period. The values would increase by a factor of two for 0.25 minutes (FAST) and decrease by a factor of two for the four minute (SLOW) measurement period.

These precisions are the theoretical values and the Gauge should yield these values if there are no instability problems. Measurement data can be used to test the Gauge.

If a series of measurements are made on the same location, the values of precision can be calculated by using:

$$\sqrt{\frac{\sum(n - m)^2}{(N - 1)}}$$

Where:

P = Precision

n = Individual measurements

m = Average of measurements

N = Number of measurements

If the actual count rate precision obtained above is divided by the theoretical precision, a test can be made of the Gauge stability. The resultant value, R will indicate electronic noise in the circuits or an unstable detector. The equation for this test is indicated in 5.5, and the Gauge has this function included in the software.

8 Radiation Safety

The user of this equipment should study the Radiation Safety Manual, which is supplied with it. If available, a formal course on the subject is desirable. While the radioactive materials in the Gauge are very small amounts and only a major accident to the Gauge could cause an immediate hazard, care should be taken in its use in order to keep exposure as low as reasonably achievable.

Remember that short time and long distance are the most effective means of minimizing the user's exposure.

Refer to the Radiation Safety Manual for more complete details of safety procedures.

8.1 Licensing

Prior to receipt and use of this equipment, the user must obtain a Radioactive or By product Material License from the government agency responsible for the purchaser's area.

The licensee must have a Radiation Safety Officer who has received training in safety and applicable regulations. He will be responsible for the initiation and maintenance of a safety program for the users. All records and inventory controls must be available for inspection.

8.2 Dosimeter

Personnel using the equipment should wear personnel dosimeters in order to assure that proper care is being taken in storage, transport and use. Some regulations allow dispensing with this requirement after a period of monitoring.

All visitors in the area of use should be kept to a minimum. If long-term observance of the use of the equipment is needed then dosimeters should be supplied. The general rule is that any individual that is likely to receive 10% or more of the regulatory maximum is required to be monitored.

Any person whose age is less than 18 years must not be exposed to any dose which is likely to exceed 10% of the regulatory maximum for radiation workers.

8.3 Wipe Tests

There is a legal requirement that the sealed capsules containing the radioactive materials in this Gauge must be tested for integrity of the seals. This test is described in detail in 5.4. The record of this test must be retained for inspection by the regulatory agency. The user's license will specify who may make the wipe and process the material.

8.4 Transport

Any equipment given to a common carrier for shipment must have a current negative leak test. The shipper must have this record in his possession along with a certification that the capsule, and transport container meet the US Department of Transportation requirements as specified in Title 49 Parts 172 and 173 of the Code of Federal Regulations these certification must be on file for one year after the shipment. For international shipment the Regulations of the international Atomic Energy Agency apply and other countries have their own regulations for domestic shipment. The consignee of any shipment other than a freight forwarder or customs agent must be in possession of a license for the radioactive materials.

A shipping paper presented to the carrier along with the package certification must contain the following information:

RQ, Radioactive Material, TYPE A PACKAGE, Special Form, UN3332

Name	Cesium-137	Americium-241
Activity	0.37 GBq (10 mCi)	1.48 GBq (40 mCi)
Category	YELLOW II	
Transport Index	0.2	
Type	A	

A record of the shipment and copies of all the documentation including a copy of the consignee's license must be retained by the shipper.

8.5 Disposal

The owner must not dispose of this equipment except under the following conditions:

- Transfer to another licensee for possession and use as covered in their license.
- Transfer to another licensee for storage or disposal as covered in their license.

8.6 Reporting of Loss or Incidents

The loss of this equipment or incidents, which may cause exposures in excess of the recommended maximums, must be reported immediately to the Radiation Safety Officer and to the government agency responsible for administering the license.

Other events, which may represent a safety hazard, must also be reported.

8.7 Radiation Profile

The maximum surface and one meter exposure rates for this equipment are listed below in mRem/h.

The Transport Index for the Transit Case and Gauge is:

Dose Rate in mRem/hr 0.2

Transit Case	Gamma	Neutron	Total
Maximum any surface	10.50	1.50	12.00
Maximum at one meter	0.07	0.10	0.17
5001 Gauge	Gamma	Neutron	Total
Rear Surface	17.00	0.30	17.30
Rear at one meter	0.10	0.00	0.10
Front Surface	2.50	0.40	2.90
Front at one meter	0.10	0.00	0.10
Bottom Surface	8.50	1.50	10.00
Bottom at one meter	0.06	0.50	0.56
Top Surface	18.00	0.70	18.70
Top at one meter	0.06	0.00	0.06
Side Surface	11.00	0.80	11.80
Side at one meter	0.20	0.00	0.20
Handle	0.80	0.50	1.30
Handle at one meter	0.10	0.0	0.10

North Carolina Protection Section Measurement Dose Rates. Gamma dose rates were measured 08/05/88 using a Ludium Model 14C Survey Meter. Neutron dose rates were measured 08/05/88 using an Eberline Model PNR-4 Neutron Rem Counter with a 22.9 cm sphere on the Gauge surface, centerline was approximately 11 cm from the surface. 0.0 indicates dose rates same as background.

9 Warranty

The purchase of this equipment includes a limited 24 months warranty against defective material and workmanship. The owner may replace defective parts in the field by prepaid shipment for installation.

Equipment shipped prepaid to the factory will be repaired or replaced at the option of HUMBOLDT and returned prepaid to the customer. This warranty does not apply if the product as determined by HUMBOLDT, is defective because of normal wear or accident or misuse, or as a result of service or modification by other than an Authorized Service Facility.

THIS EQUIPMENT CONTAINS HAZARDOUS RADIOACTIVE MATERIALS AND THE PROPER USE OF THE EQUIPMENT AND PROTECTION OF FACILITIES AND PERSONNEL IS SOLELY THE RESPONSIBILITY OF THE PURCHASER. OWNERS AND USERS ACCEPT RESPONSIBILITY FOR COMPLIANCE WITH LOCAL AND NATIONAL LAWS COVERING THE POSSESSION, USE AND DISPOSAL OF THE MATERIALS.

THERE ARE NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS, WHICH EXTENDS BEYOND THIS DESCRIPTION. THIS EXPRESS WARRANTY EXCLUDES COVERAGE OF AND DOES NOT PROVIDE RELIEF FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND OR NATURE, INCLUDING BUT NOT LIMITED TO LOSS OF USE, LOSS OF SALES OR INCONVENIENCE. THE EXCLUSIVE REMEDY OF THE PURCHASER IS LIMITED TO REPAIR, RECALIBRATION OR REPLACEMENT OF THE EQUIPMENT AT HUMBOLDT'S OPTION.

Specifications and descriptions are as accurate as possible. HUMBOLDT reserves the right to make changes and improvements in accordance with the latest specifications and design improvements. Upgrading of older equipment to current specifications will be made, where possible, at the expense of the current owner except where HUMBOLDT may elect to make the upgrade at no cost to the owner.

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Testing Equipment for



Construction Materials

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NUCLEAR GAUGES