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FAX TRANSMITTAL

Date: 9-24-08

Project:

TO: Roberto Torres
NRC

FROM:
Colleen Boeshans

Phone:
Fax:

Number of Pages: including cover

Re: Lic. No. 25-27592-01 Boesh Engineering

Remarks:

Mr. Torres,

Please give us a call if you have any more questions.

Thanks,
Colleen B.

5001 SERIES

COMPACTION CONTROL GAGES

INSTRUCTION MANUAL

Richard L. Berry

Page 7 Section 1.34 Last Paragraph

Surface Dose Rate — 40 mRem/hour maximum
Transit Case — USDOT 7A, Type A, Yellow II Label, 0.2 TI

Page 8 Section 1.35 Power Source

Change from: Six alkaline D size batteries
to: Six alkaline AA size batteries

Change from: 6000 Operating hours
to: 1200 Operating hours

Change from: 4000 Operation hours
to: 800 Operating hours

Page 8 Section 1.38 Gage Weight

Change from 18 kg to 13.7 kg.

Page 56 Under Section Battery Replacement

Change second paragraph "D size" to "AA size"

Replace third paragraph with:

Remove the Processor Panel using the four thumb screws. Remove the two screws clamping the battery retainer and replace the batteries with the polarities as indicated.

Page 76 Under Section 9.4

Category	YELLOW II
Transport Index	0.2
Type	A

9.7 Radiation Profile

The maximum surface and one meter exposure rates for this equipment are listed below in mRem/h. The gamma dose rates are normalized for 10 mCi of Cs-137. The neutron dose rates are calculated based upon a 40 mCi Am-241:Be source producing 8.3 X 10^4 n/s.

The Transport Index for the Transit Case and Gage is 0.2.

Transit Case	Gam(1)	Gam(2)	Neu(1)	Neu(2)	Total
Maximum any surface	10.3	10.5	10.7	1.5	12.0
Maximum at one meter	0.12	0.07	0.06	0.1	0.17
5001 Gage					
Rear Surface	16.7	17.0	2.3	0.3	17.3
Rear at one meter	0.14	0.1	0.06	0.0	0.10
Front Surface	2.9	2.5	1.8	0.4	2.9
Front at one meter	0.12	0.1	0.06	0.0	0.10
Bottom Surface	9.7	8.5	37.4	1.5	10.0
Bottom at one meter	0.07	0.06	0.08	0.5	0.56
Top Surface	15.9	18.0	6.8	0.7	18.7
Top at one meter	0.23	0.06	0.07	0.0	0.06
Side Surface	10.1	11.0	8.7	0.8	11.8
Side at one meter	0.17	0.2	0.07	0.0	0.20
Operator Panel Surface	3.6		14.7		
Handle	1.7	0.8	0.50	0.5	1.3
Handle at one meter	0.04	0.1	0.04	0.0	0.1

(1) Manufacturers Stated Dose Rates.
Gamma dose rates were measured 03/14/87 using a Victoreen Model 471 Ionization Chamber.
Neutron dose rates were calculated 03/14/87 using fast neutron dose conversion tables from Title 10CFR20.
Dosimeter measurements on the bottom surface indicated 25.5 mrem/hr

(2) NC Radiation 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 gage surface, centerline was approximately 11 cm from the surface. 0.0 indicates dose rates same as background.

4.1 Backfill Compaction in Trenches

If direct transmission is used, no precautions in density are necessary other than being sure that the tip of the source rod is at least 50 mm (2 inches) above any pipe which may be buried in the trench. If backscatter is used, the pipe must be at least 150 mm (6 inches) below the surface.

Moisture measurements require a special procedure. The effect of the sidewall is automatically determined and compensated for in the Processor version, by a relatively simple procedure which follows:

a. Place the reference standard in the trench and the gage on top of the reference standard such that the gage is in the same orientation and distance from the sidewall as when the density test will be performed.

b. Press and hold the SHIFT key and simultaneously press the NORM MEASUREMENT key. (Any of the MEASUREMENT keys may be used, but NORM is recommended.) NOTE THAT "-H" APPEARS IN THE LEFT PORTION OF THE DEPTH DISPLAY. THE "-H" WILL APPEAR IN THE DISPLAY AND A NEGATIVE VALUE WILL REMAIN IN THE MOISTURE COUNT REGISTER UNTIL THE MOISTURE CORRECTION IS USED FOR AN ACTUAL DENSITY TEST EVEN IF THE GAGE IS TURNED OFF BEFORE THE TEST IS PERFORMED. The gage will count for 1 minute, subtract the MOISTURE COUNT from the MOISTURE STANDARD COUNT, and store the result in the MOISTURE COUNT register. When the next density test is performed, instead of incrementing the MOISTURE COUNT from 0, the MOISTURE COUNT will increment from the negative value stored in the MOISTURE COUNT register.

```
*****************************************************************
* THE TRENCH CORRECTION DETERMINED IN THIS MANNER IS VALID      *
* FOR ONLY ONE LOCATION IN THE TRENCH AND THEREFORE WILL        *
* ONLY REMAIN IN THE MOISTURE REGISTER FOR ONE TEST.  THE       *
* MOISTURE CORRECTION PROCEDURE IN b. ABOVE MUST BE             *
* PERFORMED AT EACH DENSITY TEST SITE IN THE TRENCH.  THE       *
* MOISTURE CORRECTION DOES NOT REMAIN IN THE MOISTURE COUNT     *
* REGISTER UNTIL REMOVED BY THE OPERATOR AS WITH SOME OTHER     *
* MANUFACTURER'S EQUIPMENTS.                                    *
*****************************************************************
```

c. The test site is then prepared and the test performed in accordance with 3.5 through 3.7 in the same location and orientation as the trench moisture determination was made.

When tests are performed using the Dual Scaler version, a MEASUREMENT COUNT is taken with gage placed on the reference standard as in "a" above and the difference between the MOISTURE COUNT with the gage on the reference standard in the trench and that day's usual standard count is subtracted from the MOISTURE MEASUREMENT COUNT at the density test site in the trench. As above, the trench correction should be determined for each density test site within the trench.

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1.1 GENERAL

This instrument, the 5001, is specifically designed to measure the moisture content and density of construction materials. This information can be used to manually calculate other parameters which are commonly used to control compaction during construction. The microprocessor based version (P) automatically computes these parameters and also makes certain corrections to the measurements which would be difficult if not impossible to make using a hand held calculator.

It uses the attenuation of gamma radiation due to compton scattering and photoelectric absorption which 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 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 owner 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 which is predominately a function of the hydrogen content of the materials and to a lessor 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. The largest single error may be caused by hydrated minerals such as gypsum or crystals such as mica. 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 calibration is based on a water saturated silica sand standard which is used to calibrate a working standard. The calibration may be altered by the user to correct for other materials.

*** 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.

The owner of this instrument must have a Radioactive or By-product Material License issued by an Agreement State (US), or Federal Authorities such as the US Nuclear Regulatory Commission.

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

"Precision" The statistical variations 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 changes with density and is stated at a density of 2000 kg/m^3 (125 PCF).

The error is not a percentage of the absolute density and cannot be converted to precision errors 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.

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

"Chemical Error" An error which 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 density and the ratio (A/Z) of the atomic mass (A) and the atomic number (Z).

The standard calibration which is supplied is based on the average attenuation of a theoretical material consisting of half limestone and half granite. The chemical error is the spread (+/-) of measurements made on these materials at a true density of 2000 kg/m^3 (125 PCF).

The error is a percentage of the absolute density and can easily be converted to errors at other densities.

"Surface Error" The error caused by surface voids. It is composed of two errors which are not easily separated. The error is determined by first making a measurement with the gage flush on a smooth surface and then repeating the measurement with the gage elevated 1.25 mm (.050 inch) over the surface. The difference in the two values is defined as the "surface error".

A portion of this error is caused by reducing the volume of measurement contained within the material being tested. In effect, a portion of the measured volume has zero density which is averaged with the density of the material.

Part of this error is caused by gamma streaming along the base of the gage. This type of error is only apparent during the testing of the instrument in accordance with the ASTM requirements. In actual field use, the streaming could not take place since a portion of the gage 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 as determined by the ASTM defined test could never appear under field conditions.

"Depth of Measurement" The depth of measurement is defined as that depth above which 95% of the measurement occurs. The balance of the measurement (5%) is determined by material below the stated depth. The value indicated by the gage is the weighted average of materials in the upper and lower layers. This is an important parameter of a backscatter type gage since a deeper depth of measurement reduces the error caused by loose surface materials or surface voids.

"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 which is a gravitational system of measurement by multiplying by .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 these units in the absolute system as "densities".

1.3 SPECIFICATIONS

1.31 MEASUREMENT (Density at 2000 kg/m^3 [125 pcf])
(Moisture at 160 kg/m^3 [10 pcf])

	SLOW	NORM	FAST	UNITS
BACKSCATTER DENSITY				
Precision	4 [0.25]	8 [0.5]	16 [1.0]	±kg/m^3 [pcf]
Chemical Error	<————	40 [2.5]	————>	±kg/m^3 [pcf]
Surface Error	<————	48 [3.0]	————>	-kg/m^3 [pcf]
Depth	<————	88 [3.5]	————>	mm [inch]
DIRECT TRANSMISSION DENSITY AT 150 mm [6 inch]				
Precision	2 [0.13]	4 [0.25]	8 [0.50]	±kg/m^3 [pcf]
Chemical Error	<————	16 [1.0]	————>	±kg/m^3 [pcf]
Surface Error	<————	8 [0.5]	————>	-kg/m^3 [pcf]
Depth	<—— 50 to 300 [2 to 12] ——			mm [inch]

	SLOW	NORM	FAST	UNITS
MOISTURE				
Precision	2.5 [0.12]	5 [.25]	10 [0.50]	±kg/m^3 [pcf]
Surface Error	<————	4 [.25]	————>	-kg/m^3 [pcf]
Depth	<—— 100 to 200 [4 to 8] ——			mm [inch]

1.32 CALIBRATION METHOD

The gages are calibrated in accordance with the method required by ASTM D2922 and D3017. Five density standards consisting of three metallic blocks of magnesium and aluminum and two mineral blocks of granite and limestone. 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%.

Four entirely different calibrations are available to the engineers or technicians controlling the use of the gage but they are not easily accessible to the operator. 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 USNBS gamma attenuation coefficients and the known density of the standards. Tables of this data are supplied with the scaler version of the gage and computerized data with the processor version.

1.33 Field Data Conversion for Processor Version

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

1.34 RADIOLOGICAL

Gamma Source	HSI 2200064
Amount and Type of Material	10 mCi (nom) cesium-137
Special Form Registration	GB/24/S
ANSI and ISO Class	C64444
Neutron Source	HSI 2200067
Amount and Type of Material	40 mCi (nom) americium-241:be
Neutron Yield	90 knps (nom)
Special Form Registration	GB/7/S
ANSI and ISO Class	E65455
Surface Dose Rate	14 mrem/hour maximum
Transit Case	DOT 7A, Type A, Yellow II Label, 0.1 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. A similar license is required by the governments of other countries.

1.35 Electrical Specifications

Displays (two)	LCD
Timer Stability	0.01%
Power Supply Stability	0.10%
Power Source : Six alkaline D size batteries	
Power Consumption	
Dual Scaler	15 milliwatts
	6000 Operating Hours
Processor	
Non-active	15 milliwatts
Active	90 milliwatts
	4000 Operating Hours
Power Protection	
Circuit Breaker	
Short Circuit Proof	
Auto Alarm for low battery condition	
Auto Shutoff for dead battery condition	

1.36 Mechanical Specifications

Materials	
Source/Index Rod	440C Stainless Steel, induction heat treated to 55 Rockwell C
Gage Base	Machined 6061 T6 Aluminum, hard coated and teflon impregnated.
Post and Frames	Machined 6061 T6 Aluminum, anodized for anticorrosion.
Top Shell	Injection Molded Noryl
Bearing	Relieved bronze with neoprene seals.
Screws/fittings	Stainless/brass, no steel.
Operating Temperature	-10 to 70 °C
	175 °C Test Material Surface
Storage Temperature	-55 to 85 °C
Humidity	98% without condensation
	Rainproof Construction
Vibration	2.5 mm (0.1 in) at 12.5 Hz
Shock	Unpadded gage meets USDOT 7A without transit case.
Gage	
Size(excluding handle)	400 X 220 X 140 mm
Height(with handle)	450 or 550 mm
Weight	18 kg
Reference Standard	
Size	350 X 200 X 75 mm
Weight	4.5 kg
Transit Case	
Size	635 X 500 X 320 mm
Weight	15.5 kg

Accessory Case(loaded)	
Size	500 X 250 X 125 mm
Weight	7.5 kg
Total Shipping Weight	45.5 kg (100 lb)

1.37 Accessories

Transit Case	Zippered Accessory Case
Reference Standard	Rod Guide/Scraper Plate
Operator's Manual	Drill Rod
Radiation Safety Manual	Four Pound Hammer
Source and Case Certification	Rod Extraction Tool
Wipe Test Materials	

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 the Appendix. This information will be helpful in understanding the limitations of the equipment and how to avoid or work around these limitations.

2.1 Equipment Supplied

Transit Case Containing	Accessory Case Containing
Gage	Rod Guide/Scraper Plate
Reference Standard	Drill Rod
Operator's Manual	Four Pound Hammer
Radiation Safety Manual	Rod Extraction Tool

Both the gage 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 Accessory Case.

The accessories are contained in a zippered canvas case which has compartments to store the various accessories including a spare drill rod if desired. It is convenient to carry and decreases the bulk and weight of the transit case which contains the Gage, Reference Standard and Manuals.

2.21 Scraper Plate/Rod Guide. When the gage is to be used on soil, the Scraper Plate is used to smooth the site to eliminate surface voids as much 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 gage base and if a line is marked around it when the rod is driven into soil, the gage can be approximately located over the rod hole before attempting to lower the gage source rod into the hole.

The plate may be used to lightly tamp soil or native fines which may have been used to fill the surface voids but must not be used with the hammer to pack soil since it will damage the plate and also cause erroneous measurements.

2.22 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. It should always be driven at least 50 mm (2 inches) deeper than the source will be placed.

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 safety glasses must be worn by the operator and others close by the test site.

2.23 Four Pound Hammer. The hammer is supplied to drive the rod into soils or soil-aggregates. It is sufficiently heavy for this purpose and a larger one is not needed and could rapidly damage the drill rod. It may also be used with the extraction tool to help remove the rod from clay.

2.24 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 tapped on the underside of the tool to drive the rod up out of the hole.

2.3 Transit Case.

The transit case is a vinyl coated high strength plywood case with aluminum edging and steel corners and is equipped with a lockable latch. The design and components follow the standard ATA case configuration which is in popular use for air shipment of delicate instruments. It has fitted and padded compartments for the gage and Reference Standard 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 US and International requirements for surface and air cargo shipment.

The case contains the Reference Standard along with either the dual scaler (S) or processor (P) versions of the 5001 Compaction Control Gage.

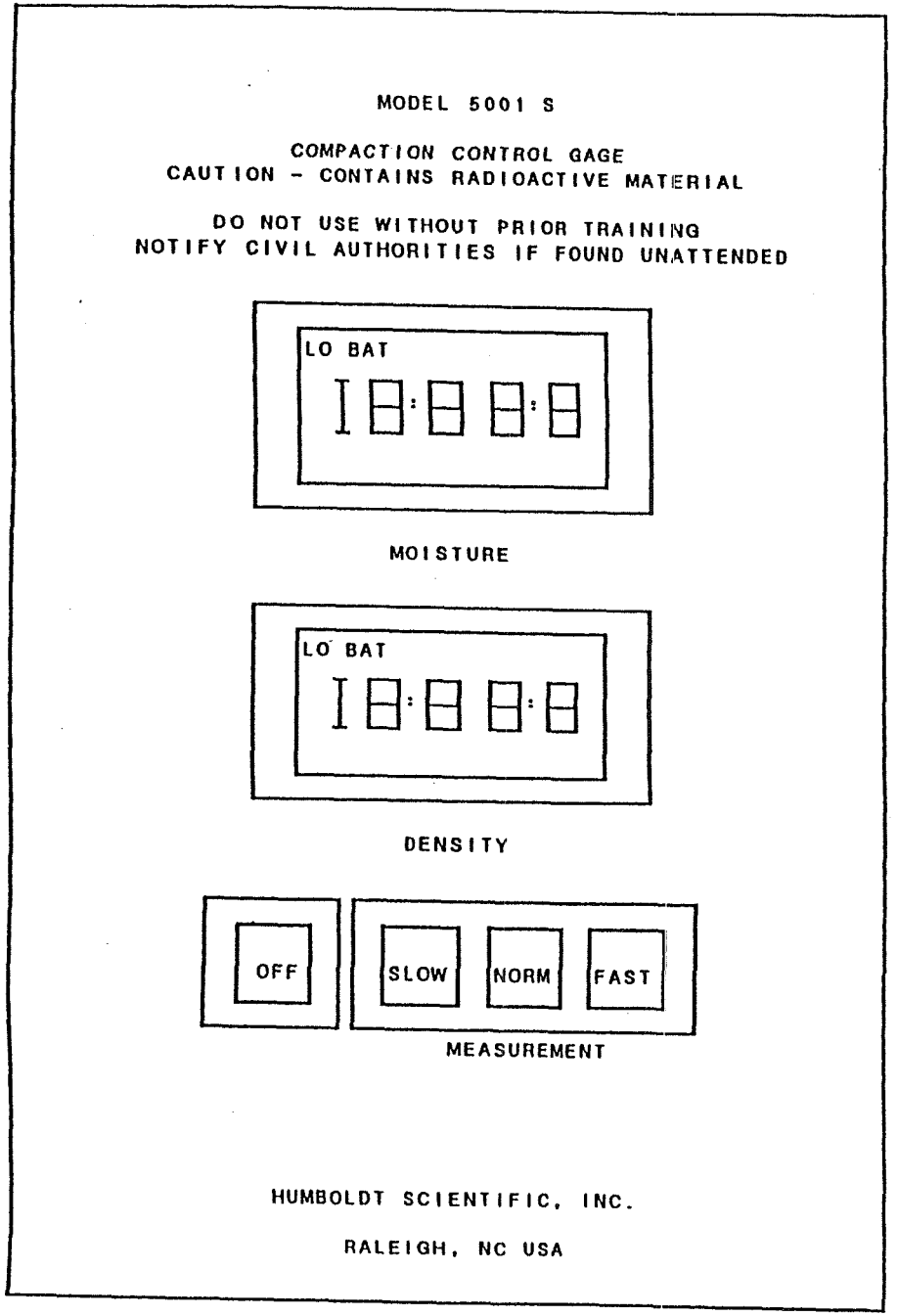
2.31 Reference Standard. The Reference Standard is used to provide a standard count to eliminate aging of the calibration. Instruments which use radiation to perform measurements are subject to drift due to decay of the source (2% per year for Cs-137), drift of the detectors due to leakage and absorption of the quench gas, and long term drift of the electronics. In order to decrease the effect of these errors, the calibration is made as a ratio to a standard measurement. The moisture count is ratioed to a count on the standard and the density count is ratioed to a count established by the Gage case.

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

2.32 Dual Scaler Gage, 5001 S. The scaler version of the 5001 type gage consists of dual counters, dual LCD displays and the necessary timing circuits to generate a SLOW (four minutes), NORM (one minute) and FAST (quarter minute) measurement periods. An additional key is provided to remove power from the instrument. Each of the MEASUREMENT keys will apply power to the gage if it is not already on when the key is pressed.

A facsimile of the control panel is shown on page 14 indicating the positions of the displays and keys. The keys are grouped across the bottom for easy access and the displays labeled for clarity.

The lettering is embedded in the plastic overlay and is not harmed by water or abrasion.



DUAL SCALER CONTROL PANEL

The keys are embossed and have tactile feedback to improve the feel of actuating the function. The button is not a part of the electrical circuit so there is no danger of a fingernail or pencil depression causing an immediate failure. The entire panel is waterproof; however any puncture at the key area will allow water to ultimately penetrate the panel and cause a key failure. There is a protective layer under the main layer and this type of failure would be very rare.

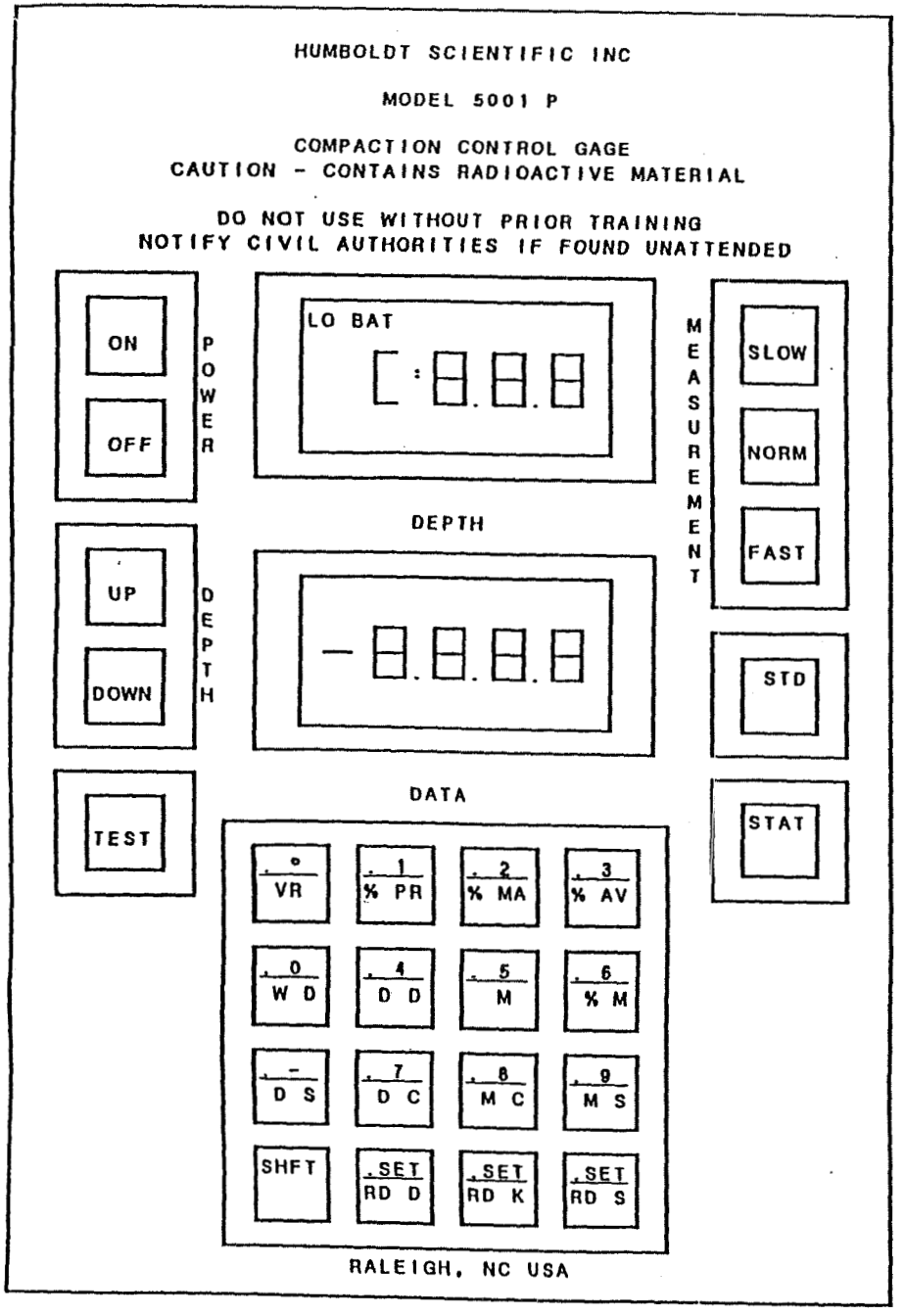
The upper display indicates the count from the moisture channel and the lower display is for the density channel. The colons are displayed during the counting period as selected by the MEASUREMENT keys. Both of the LO BAT symbols are displayed when the system batteries are getting within one to two months of depletion.

2.33 Processor Gage, 5001 P. Many features of the Processor Gage are similar to the Dual Scaler. The front panel, labeling and keys are manufactured in the same fashion and have the same protection. Many different functions are available to eliminate the necessity of tables and another calculator to compute the parameters necessary for compaction control.

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. It also allows the operator to enter a correction factor (K) to compensate for hydrogen found in construction materials which is not represented by water.

The processor has direct access to count rate data which is not truncated by the prescale as found in the scaler type gage. This eliminates some errors at high densities in the backscatter and some of the deeper direct transmission modes. The human errors involved in recording data, entering it into other calculators and computing the results are eliminated.

A facsimile of the Processor Gage control panel is shown on page 16. Since there are many functions available, a description of the purpose for each key is necessary. There are no rotary or other mechanical switches which eliminates the poor reliability found in these devices.



PROCESSOR CONTROL PANEL

The keys are color coded on the actual panel. To a degree, this is indicated on page 16 by the location of the key label. All functions labeled on the upper half of the key pad have a light blue background. The keys with double functions also have a light blue background on the upper half. This indicates that these functions are obtained by first pressing and holding the "SHIFT" (also light blue) key while pressing the desired key.

"DEPTH" display. This display primarily indicates the depth to which the measurement is being made and also serves as a system status indicator.

The depth indication will be in SI or inches as desired by the user. If a backscatter measurement is selected, the display will be " b ", and for all others will be the actual depth.

If a low battery condition exists, the display will indicate "LO BAT" in the upper left corner. The batteries will have to be replaced within the next one to two months.

If the system is making a measurement or counting, this display will have a "C:" on the left. As an example "C: 10" indicates that the system is counting and that the data to be used for processing will be the 10 inch calibration. The depth is set by the operator by using the "UP/DOWN" keys, it is not controlled by the depth to which the source rod is positioned.

The displayed depth setting is not significant while the measurement count is being made, only when the processor is being used to compute data. If it is not correct while processing, an error will exist in the computed data.

This display will also indicate an error condition if the operator has created a situation which cannot be corrected by the processor. This will be "H: XX" where the XX refers to an error number.

While a "STAT" test is being performed, the display will indicate "S:".

"DATA" Display. This display will automatically contain the density count while a measurement is being made unless the operator selects another function such as displaying one of the other counts such as "DS", "MC", or "MS".

At the end of the test, an R value for each of the channels is computed. These may be read by pressing:

"DS"	DENSITY average count
"DC"	DENSITY R value
"MC"	MOISTURE R value
"MS"	MOISTURE average count

If the R values fall within 0.6 and 1.4 the gage is stable. If the values are outside of 0.5 and 1.5 the gage requires service. Values between 0.5 and 0.6 or 1.5 and 1.6 indicate that another STAT test should be made to verify the results. A second result outside of these limits indicates the need for service.

Repeatedly pressing the "RD S" key will allow the operator to scan through the 16 one minute counts which were taken for the MOISTURE and DENSITY channels.

Pressing any one of the "MEASUREMENT" keys ("SLOW", "NORM", or "FAST") will exit the "STAT" routine and remove the "S:" flag from the "DEPTH" display. All other keys are inactive and the processor will ignore them.

"SLOW/NORM/FAST" MEASUREMENT Keys. These keys initiate a measurement after the gage has been placed on the desired location and the source rod lowered to the correct position. The periods of measurement are 4.0, 1.0, and .25 minutes respectively. These periods were chosen for a statistical difference of a factor of 2 to 1. The longer time period improves the precision by the square root of the time increase.

When any one of the keys are pressed, a "C:" appears in the "DEPTH" display. This flag disappears when the count is complete and the data is stored by the processor for later use.

While a MEASUREMENT is being made, the DENSITY COUNT, will automatically be displayed in the DATA display. Pressing "MC" will display the MOISTURE COUNT or the "DS" and "MS" keys will display the respective STANDARD COUNTS.

"DS/DC/MC/MS" Keys. These keys display the DENSITY STANDARD, DENSITY COUNT, MOISTURE COUNT or MOISTURE STANDARD counts in the DATA display.

During periods when no standards or measurements are being made, the results of the last previous counts will be displayed. During a STANDARD COUNT period, the processor automatically puts the density channel in the display but pressing "MS" will allow display of the moisture channel. Both values will be incrementing.

Either the "DC" or "MC" keys may be pressed during the STANDARD COUNT period but the values displayed will be the standard counts and not the last measurement counts. The processor is placing the standard counts in both the standard count and moisture count registers.

During a MEASUREMENT COUNT period, the processor automatically puts the DENSITY COUNT in the DATA display. Pressing the "MC" key will display the MOISTURE COUNT. Both values will be changing.

Either the "DS" or "MS" keys may be pressed during the MEASUREMENT COUNT period. The data will be fixed values of the last previous STANDARD COUNTS taken.

"WD/DD/M/% M" Keys. These keys are used to compute the WET DENSITY, DRY DENSITY, MOISTURE CONTENT and PERCENT MOISTURE. The result will be in units of kilograms/m^3 or pcf depending on the measurement system selected.

The moisture measurement values may be corrected by using the "K" function. This will change the "DD", "M", and "% M" results.

"% PR" Key. This key is used to compute the percent compaction based on a Proctor density which has been determined by a laboratory test. The calculation involves the DRY DENSITY as a percentage of the optimum density.

The optimum density must have been previously entered by using the "RD D/SET" keys along with the numeric keys.

"% MA" Key. This key is used to compute the percent compaction based on a MARSHALL or other laboratory test to determine the maximum density of an asphaltic concrete mix design. The calculation involves the WET DENSITY as a percentage of the maximum or optimum density.

It also indicates the result of all computed functions or data entry as selected by the operator. The decimal location will always be controlled by the processor to indicate four significant figures where relevant.

"ON/OFF" Power Keys. The use of these two keys is evident by their labels. When the system is first powered up by pressing the "ON" key all of the system is powered. Initially, the processor has no instructions but it does "remember" all data from the last time it was used. It puts the last depth used into the "DEPTH" display, zeros into the data display and then the processor shuts down to await some instruction.

Pressing the "OFF" key shuts the entire system down except for a very small amount of power required to monitor the power keys.

"TEST" Key. The test key checks the operation of the processor and displays. Pressing it at any time will display all segments of the displays for about 1 to 2 seconds with the exception of the "LOW BAT" symbol which is displayed only during a low battery condition. At the end of the period, the "DEPTH" display will be blank and the "DATA" display will indicate the gage serial number. Pressing any other key will restore operation of the displays.

"UP/DOWN" Keys. These keys control the "DEPTH" display and select the correct sets of calibration data which the processor will use to compute the desired measurements. Each press of the "UP" or "DOWN" key will advance the display in the selected direction to the next calibrated position. It will display in either mm or inch dimensions depending on which units are in use. It will not indicate uncalibrated positions.

As an example, if the instrument was purchased with 50 mm (2 inch) increments, the "UP/DOWN" keys will not select the 25 mm (1 inch) increments. They will skip over them and will also wrap around the upper and lower limits of the calibrated depths.

"STD/SHIFT" Key. This key and the SHIFT key forces the processor to take a SLOW (4 minute) count in both the moisture and density channels and retain the values so that they can be used to ratio all of the subsequent MEASUREMENT counts.

The gage must be positioned on the REFERENCE STANDARD with the base seated in the recess on the top of the standard. The source rod end of the gage should be over the handle end of the standard and the end of the gage firmly pressed against the top of the handle which serves as a stop. The source rod handle must be in the SAFE (top) position and the indexer latched.

When power is first applied to the gage, the "STD" counts from the prior use are still retained in memory. These counts should be replaced each working day. If the gage is switched off during a working day, either intentionally or accidentally, it is not necessary to take a new set.

The "STD" count can also be taken and stored with a more accurate result by using the "STAT" key. This uses a 16 minute average and reduces the error by a factor of two. It also performs other tests on the system.

The values of the MOISTURE and DENSITY STANDARD COUNTS should be recorded in a log book to provide a history over long periods of time in order to determine the need for service. As covered earlier, these counts will change slowly with time, but, if there is a sudden or rapid change in a few days or weeks, it is an indication of a malfunction in the system or an operator error in running the procedure.

As a rule, if a STANDARD COUNT has changed by more than the square root of the average of the last four STANDARD COUNTS, there is a possible malfunction.

"STAT/SHIFT" Key. This key and the "SHIFT" key initiate a statistical test of the moisture and density channels as described in 6.5 and 8.3. It also provides 16 minute average STANDARD COUNTS as covered under the "STD" key. The gage must be placed on the REFERENCE STANDARD and the source rod handle latched in the SAFE position.

When the test is initiated, "S:" will appear in the "DEPTH" display and remain there until the procedure is exited by pressing one of the MEASUREMENT keys.

The maximum or optimum density must have been previously entered by using the "RD D/SET" keys along with the numeric keys.

"VR" Key. This key is used to compute the VOID RATIO based on the measured dry density and the specific gravity of the solids. The specific gravity is determined by a separate laboratory test on the material and no rock correction is applied.

The specific gravity must have been previously entered by using the "RD S/SET" keys along with the numeric keys.

"% AV" Key. This key is used to compute the PERCENT AIR VOIDS of the material and is based on the DRY DENSITY, MOISTURE CONTENT and the specific gravity of the solids. The specific gravity is determined by a separate laboratory test on the material and no rock correction is applied.

The specific gravity must have been previously entered by using the "RD S/SET" keys along with the numeric keys.

"0 to 9/-/./SHIFT" Keys. The numeric keys are located on the top half of the top 12 keys in the key matrix. It is necessary to press and hold the "SHIFT" key to make use of them.

These keys are used whenever the "SET" keys are used along with the "RD D", "RD K", or "RD S" keys. Whenever any of the latter keys are pressed the previously stored value of the variable is put into the display. Pressing the "SET" key for the variable read will replace the value into memory. If the wrong "SET" key is pressed, the processor will ignore the instruction. Pressing any other function key will abort the "RD 'X'" function.

Pressing any one of the numeric, sign, or decimal keys will blank the display and the key pressed will be entered into the most significant position. As additional keys are pressed, the values will be entered across the display from left to right. The decimal (.) must be entered in its proper position in the sequence. The sign (-) key may be pressed at any time during the entry routine. If more keys are pressed than necessary to fill the display, the display will be cleared and the entry must be repeated.

After the entry is complete, pressing "SET/SHIFT" for the particular variable will place the value into memory.

"RD D" and "SET/SHIFT" Keys. These are used to read and set D. As previously covered, this is the optimum or maximum density of the material being tested. The value is used to compute percent compaction from either the WET or DRY DENSITY depending on whether the "% PR" or "% MA" keys are used.

The "RD D" key will display the value presently in memory and "SET" will store the value displayed into memory. Refer to the numeric key description to obtain the procedure for changing the value.

"RD K" and "SET/SHIFT" Keys. These keys are used to read and set K. As previously covered, this is the correction factor which is used to compensate the MOISTURE measurement for hydrogen in the material which is not in the form of free water or for materials which may have chemical elements which absorb thermal neutrons. The value entered will affect the computed values of MOISTURE CONTENT, DRY DENSITY, and PERCENT MOISTURE.

There are three methods of determining the proper value of K to be used:

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

The equation is:

$$K = \frac{\%M(oven) - \%M(gage)}{\%M(gage) + 100}$$

(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 K can be determined by systematically changing the stored value of K until the correct PERCENT MOISTURE is computed by the gage while retaining the same measurement data in memory.

(C) If no other method is available to verify the gage moisture calibration, the PERCENT AIR VOIDS may be utilized to determine if major errors exist.

Well compacted soils should have a 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 gage is measuring an excessive amount of water and a more negative value of K should be used.

Changing the value of K by ±0.001 will cause an approximate ±0.1 percent change in the computed PERCENT MOISTURE. If absolutely nothing is known about the material, set K to 0.000.

Typical values of K will range between -0.000 and -0.100. Other materials with a very high hydrogen content such as the hydrocarbon present in coal could cause the proper value to be as high as -1.000. Very few materials will require a positive value except for soils containing large amounts of boron.

The values of K which have been determined for a particular soil type should be recorded along with an identification of the soil so that it may be used in the future when similar materials are encountered.

The "RD K" key will display the value presently in memory and "SET" will store the value displayed into memory. Refer to the numeric key description to obtain the procedure for changing the value.

"RD S" and "SET/SHIFT" Keys. These keys are used to read and set the specific gravity of the solids contained in the materials being measured. The procedure for their use is the same as that described for the other read and set keys and the operation of the numeric keys.

The specific gravity must have been obtained from standard laboratory procedures such as the hydrometer test or volumetric bottles. The value will be in the range of 2.600 and 2.800.

The value stored in memory will be used to compute the VOID RATIO and PERCENT AIR VOIDS. If these results are not being used, the value is not required to be placed in the processor.

2.34 Indexing Mechanism. A reliable indexing mechanism is required in instruments of this type since the repeatability of measurements in the field and duplication of the calibration is seriously affected by the relationship between the radioactive material and the detectors. The 5001 accomplishes this by using a simple latch which positively positions the rod and is not subject to damage by continual use.

When unattended or not in use, a padlock is placed through a hole in the handle. This prevents accidental or unauthorized use of the gage. Remove the padlock. The latch is engaged and the rod cannot be moved. This is the "safe" position which is normally used while making MOISTURE and DENSITY STANDARD COUNTS. This also keeps the gamma emitting radioactive material inside of the heavy shield in the gage base and limits operator exposure.

The LATCH is the black knurled knob on the end of the handle. Rotate the knob 1/4 turn counter-clockwise and the LATCH will release. The rod can now be moved down or up with little resistance and the light spring pressure on the indexer will allow the operator to hear and feel the notches in the index rod.

When the approximate desired position is reached, rotating the knob 1/4 turn clockwise will engage the LATCH and force the indexer into the rod notch and result in very accurate positioning.

The gage should <u>not</u> be picked up with the LATCH engaged in any notch other than the "safe" position as this will unnecessarily expose the operator to gamma radiation.

When the gage is left unattended the handle should be latched in the safe position and the padlock secured through the hole in the handle.

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 exposure.

The operation will be detailed for the processor version of the gage. No computational functions are available for the dual scaler version. After making STANDARD COUNTS and MEASUREMENT COUNTS, the values are ratioed and the result is used with the calibration tables to obtain WET DENSITY and MOISTURE CONTENT in units listed in the tables. These values can then be used to calculate the DRY DENSITY and PERCENT MOISTURE using standard civil engineering definitions. From these, any of the other functions may be calculated if the optimum density and specific gravity are known.

3.1 Transportation of the Equipment

The Gage and Reference Standard should be transported in its Transit Case which is designed for this purpose. The gage lock and the case lock should be in place and secured. In the event of an accident to the vehicle, the locks will prevent unauthorized access to the radioactive material and the case will help protect the equipment from damage. The 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 Gage 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 unauthorized removal.

3.2 Standardization of the Gage

Prior to use of the gage, 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.

Before taking the STANDARD COUNT, the Gage should have been powered on for ten or more minutes. This can be easily accomplished by turning it on prior to leaving for the construction site. The batteries will last for 6000 hours in this condition so this habit will have little effect on battery replacement. If the LO BAT flag is displayed, a note should be made to replace the batteries at the next opportunity.

If the Gage has not been on for more than ten minutes, always discard the first set of counts.

Remove the Gage lock and make certain that the handle is latched in the "SAFE" position. It must be in the top position of the index rod with the latch turned fully clockwise to immobilize the handle.

Place the Reference Standard on compacted material with the recessed side up and the handle away from the operator. Place the gage on the standard with its base firmly in the recess and the source end of the gage at the handle end of the standard. The Gage base must be firmly pushed against the standard handle which acts as a stop or index.

If the Gage is a dual scaler version simply press the "SLOW" key and after four minutes, record the DENSITY and MOISTURE STANDARD COUNTS.

If a processor model is used, press "SHIFT" and "STD" or press "SHIFT" and "STAT" depending on which function is desired. The manufacturer recommends using "STAT" even though 16 minutes are required instead of four. The STAT routine provides more accurate STANDARD COUNTS and checks the stability of the Gage.

If "STD" is used, the "DEPTH" display will indicate "C:" while the count is being made and after it is complete the "C:" will be erased and the data will be stored by the processor for later use. The values may be placed in the "DATA" display by pressing "DS" and "MS".

If "STAT" is used, the "DEPTH" display will indicate "S:" and the "DATA" display will indicate " 16". The latter value will decrement as time passes and indicates the time left before completion. After completion the DENSITY R value will be displayed in "DATA". Pressing "DS" and "MS" will display the two standard counts. Pressing "DC" and "MC" will display the R values which should be between 0.6 and 1.4. If the values are outside these limits, the test should be rerun and if the second test fails, return the Gage for service.

After the test is complete and while "S:" is in the "DEPTH" display, the individual one minute counts may be obtained by repeatedly pressing "RD S".

All of the other keys with the exception of the MEASUREMENT keys are inactive. Pressing any one of "SLOW", "NORM" or "FAST" will exit the STAT routine, and remove the "S:" from the "DEPTH" display.

Replace the REFERENCE STANDARD in the TRANSIT CASE as it will no longer be needed. Switching off the Gage will not require that the process be repeated as the data is retained in memory.

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 5001 processor Gage.

3.31 Optimum or Maximum Density. For any type of material, an optimum or maximum density is required in order to calculate the percent compaction. For soils, this is normally a laboratory Proctor density. For asphaltic materials, the Marshall or a maximum density is used.

The degree of compaction based on a percentage of a Proctor is a function of the measured dry density and is obtained by pressing "% PR". For asphaltic materials, it is a function of the wet or total density and is obtained by pressing "% MA".

Press "RD D" to display the current value of the optimum density retained in memory. If it is not correct, enter the proper value by using the numeric keys as described in Chapter 2. Press "SHIFT" and "SET" (over "RD D") to store the new value. Pressing these keys without changing the value simply stores the old value.

3.32 Moisture Correction Factor (K). Moisture measurements using neutron thermalization has a bias based on hydrogen not contained in water and thermal neutron absorbers. A correction for this error may be utilized as covered in Chapter 2.

If the factor is not known it may be determined by the procedures indicated in Chapter 2. If no correction is to be used, the value is 0.000. To determine the value presently in the processor, press "RD K".

To set a new value, use the numeric keys and then press "SHIFT" and "SET" (over "RD K").

3.33 Specific Gravity. The specific gravity of the measured material solids is required in order to compute the VOIDS RATIO or PERCENT AIR VOIDS. This value is determined by standard laboratory tests.

Press "RD S" to display the value currently stored in memory. If this is not the correct value it may be changed by using the numeric keys and replaced by using "SHIFT" and "SET" (over "RD S").

If the correct value is not known, an average value of 2.700 (or other estimated value) may be used, realizing that computed values involving voids will be in error.

3.4 Site Selection

In general, all measurements 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 measurements. Any rain prior to the measurement 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 gage. 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 direct transmission measurements 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 and the surface voids must be carefully leveled with a 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 50 mm (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 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 rod to remove it. If the 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 a light mark is drawn around the Scraper Plate while it is placed over the hole, it will be easier to locate the Gage such that the source rod will extend into the hole without difficulty.

3.6 Positioning the Gage

Carefully place the Gage over the prepared site. If backscatter is used, seat the Gage 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 rotating the knob counterclockwise and push the handle down until the approximate correct position is obtained, the first notch for backscatter or the correct predetermined depth for direct transmission. One can count the notches by feeling or hearing the "click" as the INDEXER passes by the notches. At the correct depth, rotate the LATCH firmly clockwise to accurately position the source.

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

3.7 Taking the Measurement Count

The measurement can be taken by simply pressing one of the MEASUREMENT keys. Most measurements will be made by using the "NORM" key which takes an exact one minute count but the elapsed time may be slightly longer due to processor overhead. It is doing some other operations while monitoring the actual counting.

It may be desirable to use the "FAST" or 1/4 minute key 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 key will enable the user to improve the precision by a factor of two which will allow close examination of small density changes such as establishing a roller pattern or attempting to improve compaction efficiency.

After pressing the desired key, the "DEPTH" display will indicate "C:" as notice that a count is in progress. The data display will indicate the density count as it progresses. Pressing the "MC" will display the progressing moisture count. "MS" or "DS" may be used to review the existing standard counts in memory if desired. All other keys are inactive with the exception of the MEASUREMENT keys which may be used to restart the count if an error is noticed.

At the end of the selected time, the "C:" in the "DEPTH" display will no longer be evident. The measurement is complete. Some users record the measurement counts as a means of keeping a history of their data.

When the counting is complete, the source rod should be retracted to the "safe" position. It is not necessary to leave it extended and the dose rate around the margin of the gage can be as high as 200 mrem/h in shallow depth and low density materials. Release the LATCH by rotating counter-clockwise and pull the handle to the top position. Relatch by rotating clockwise. It is not necessary to replace the padlock unless testing is complete for the day.

It may be convenient to leave the gage on the test site until the data is processed in the event that another test is needed.

3.8 Processing the Results

For the Dual Scaler type Gage, simply divide the MEASUREMENT COUNTS by the STANDARD COUNTS to obtain ratios and refer to the calibration tables to obtain the WET DENSITY and MOISTURE CONTENT. 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. Other parameters may be calculated as may be required.

When using the Processor type Gage, these functions are performed by the computer to produce the results without consulting tables or transferring data to a hand held 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 "DEPTH" display must indicate the actual depth at which the measurement was made. This is set by using the "UP/DOWN" keys. The display will only indicate calibrated depths and the value will be in millimeters or inches as preset in the instrument.

The K factor should have previously been placed into the processor as explained in 3.32.

Pressing "WD", "DD", "M" and "% M" will produce the above results so that they may be recorded on a suitable data sheet along with other site identification.

3.81 Compaction Control. Generally it is desirable to obtain compaction as a percentage of an optimum 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 density has been placed in the D register by using the "RD D" and "SHIFT/SET" keys as described in 3.31, the PERCENT COMPACTION can be obtained by pressing "% PR" to obtain the percentage of the DRY DENSITY to the optimum density or pressing the "% MA" to obtain the percentage of the WET DENSITY to the maximum density.

3.82 Void Ratio. By definition, the void ratio (ε) 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 2.700 may be used to yield approximate void ratios.

The specific gravity may be entered by using the "RD S" and "SHIFT/SET" keys as described in 3.33. Pressing "VR" will perform the the necessary calculations and display the result in "DATA". 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 optimum or maximum density is not known.

3.83 Percent Air Voids. This term is defined as the 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 3.33. If the calculation is made for asphaltic concrete, the normal PERCENT MOISTURE calculation for soils will have to be adjusted by using "RD K" and "SHIFT/SET" to agree with the asphalt content of the mix. The calculation is performed by pressing "% AV" and the results will be displayed in "DATA".

"% AV" is an indication of the degree of compaction <u>and</u> 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 K factor 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 K factor in a positive direction (not necessarily a positive number but perhaps a less negative one).

3.9 Repacking the Equipment

After use, secure the equipment. First, latch the handle in the "safe" position and install the padlock. After wiping the Gage 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 case to prevent loss.

4 SPECIAL TESTS

There are many other applications for moisture and density measuring equipment other than compaction control for highway construction and foundations. Some of them require special handling of the equipment or resulting data.

4.1 Backfill Compaction in Trenches.

Making measurements in a trench requires some precautions due to the effect of the trench wall on the Gage. Extra shielding of the detectors have minimized these effects on the 5001 if a few precautions are taken.

The Gage should not be used in a trench where the distance between the walls is less than 600 mm (24 inches). When the STANDARD COUNTS are made, they should be done in the trench if the point to be measured is less than 400 mm (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 Gage should be facing the closest wall of the trench.

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

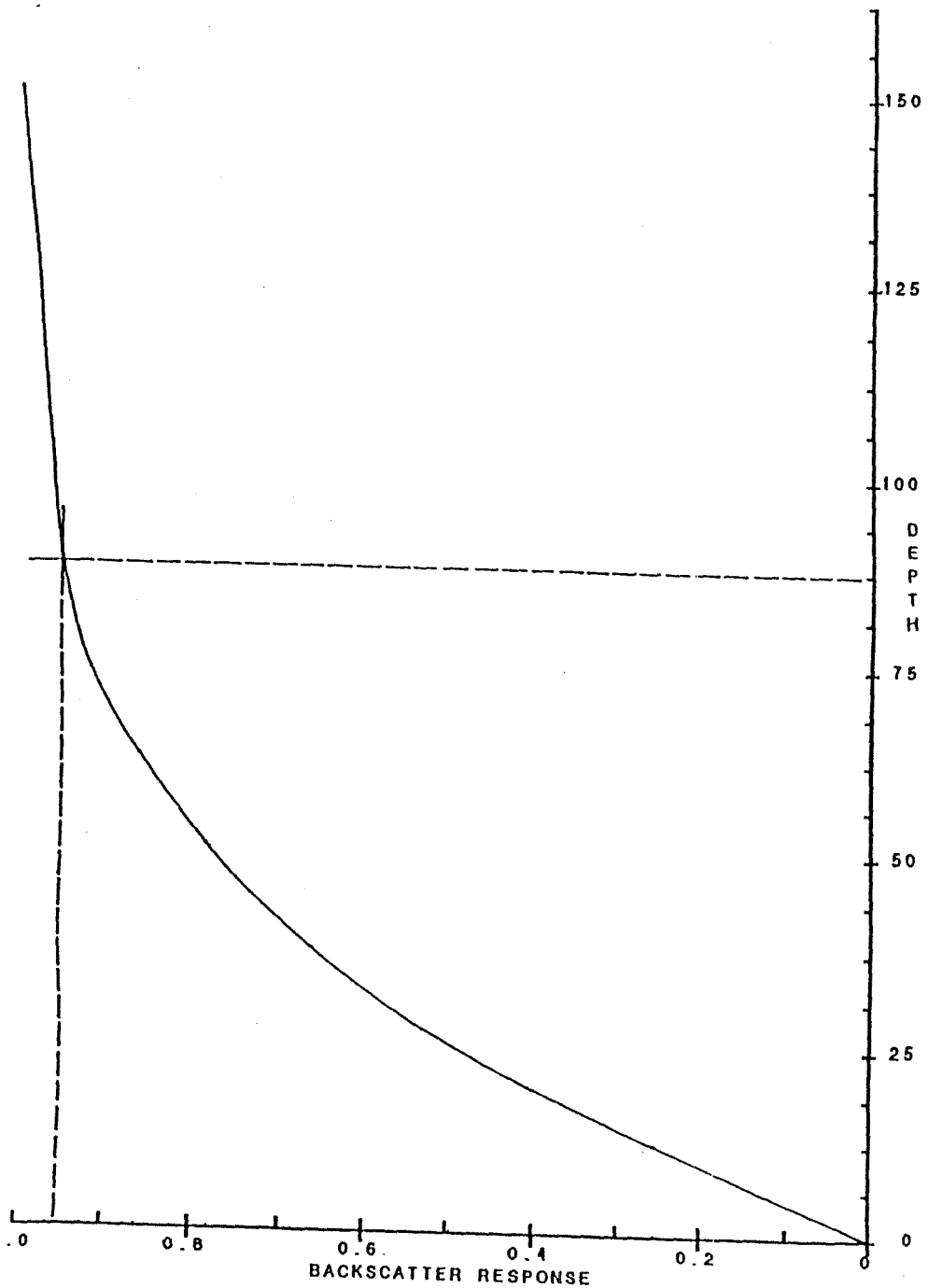
If a pipe line is involved and direct transmission is used, the end of the source rod should be no closer than 50 mm (2 inches) from the pipe. For backscatter, the pipe should be more than 150 mm (6 inches) below the surface.

If the pipe is full of water, no moisture measurement should be made at less than 250 mm (10 inches) from the pipe.

4.2 Control Strip for Treated Bases.

When very open graded bases are used, there are sometimes very large surface voids. If tight specifications are involved, it is sometimes difficult to obtain passing results for the material and over compaction may result.

The relatively high backscatter precision and low surface effects of the 5001 will overcome this problem in most conditions. Some mixes, using pure granite or pure limestone aggregates combined with the other errors require other procedures. The Virginia Highway Research Council developed a control strip method to overcome these problems and accelerate testing by eliminating any surface filling.



The procedure involves laying a test section of approximately 100 m (300 feet) long. Gage density measurements are taken between successive roller passes at prescribed locations and a plot of the density is made. The rolling continues through breakdown until a maximum density is reached.

During construction, the maximum density reached is the target, with the passing limit set at 98% of this value. Tests are run on 2800 m^2 (2000 yd^2) sections and the average of five tests is used to establish passing conditions. Each test must be 95% or higher and the average must be no less than 98%.

The method has been very successfully used and details may be obtained from the Council.

4.3 Thin Lift Measurements.

The 5001 has been designed to be as sensitive as practical in the backscatter mode in order to minimize surface errors. Because of this, 95% of the measured volume extends down to 88 mm (3.5 inches) below the surface and 5% extends below that depth.

The Gage RESPONSE versus DEPTH is shown graphically on page 36 and the table below contains the data used to create the graph.

mm	in.	RESP	mm	in.	RESP	mm	in.	RESP
0	0.00	0.000	56	2.25	0.821	113	4.50	0.975
6	0.25	0.150	63	2.50	0.858	119	4.75	0.980
13	0.50	0.258	69	2.75	0.890	125	5.00	0.985
19	0.75	0.387	75	3.00	0.912	131	5.25	0.989
25	1.00	0.490	81	3.25	0.932	138	5.50	0.993
31	1.25	0.583	88	3.50	0.945	144	5.75	0.996
38	1.50	0.658	94	3.75	0.955	150	6.00	0.998
44	1.75	0.721	100	4.00	0.960	156	6.25	0.999
50	2.00	0.778	106	4.25	0.968	163	6.50	1.000

The data indicates that the Gage is sensitive to density changes to depths as great as 165 mm (6.5 inches) but, from a practical standpoint, the Gage 2σ precision of 16 kg/m^3 (1 pcf) represents about 0.7% at the mid density range which fixes the absolute maximum depth of measurement at about 150 mm (6 inches).

In most applications where thin sections of paving are put in place, there is seldom a great difference in the density of the top and bottom layers. Assuming a maximum of 10%, it is not necessary to make corrections if the top layer is more than 88 mm (3.5 inches) thick. Even under these conditions, the maximum error created by ignoring the bottom layer is only 0.5% (5% of 10%).

Considering all sources of error, the manufacturer does not recommend that corrections be applied if the top layer is 75 mm (3 inches) or more in thickness. This assumes an error limit of 1%.

An example of the correction procedure follows:

Assume a condition where a 50 mm (2 inch) mat is being placed over an old surface with an average density of 2400 kg/m^3 (149.8 pcf) and the Gage measurement indicates a density of 2306 kg/m^3 (144 pcf). The Gage RESPONSE at 50 mm is .78.

The corrected density of the top layer is:

$$Dt = \frac{Dm - Db*(1-R)}{R}$$

Where: Dt = Density of top layer
Dm = Density measured
Db = Density of bottom layer
R = Gage response at specified depth

The top layer density of the example is 2279 Kg/m^3 (142.3 pcf).

A simple nomograph may be constructed from the above data to perform the calculation without the use of a hand held calculator.

While theoretically this correction could be made for layers of any thickness, there is a lower limit where variations in the bottom layer density and the actual thickness of the top layer become very critical and could produce dramatic errors. Unless the thickness of the compacted layer can be very carefully controlled or measured, the correction should not be used at less than 38 mm (1.5 inches).

The 5001 is capable of retaining four different calibrations at any time and they may be selected by using switches which are located on the rear panel. They may be used with either the International System of units yielding density in kilograms per cubic meter (kg/m^3) or the inch pound system yielding unit weight in pounds per cubic foot (pcf).

A Field calibration may be installed by owners or their designated service suppliers. It may also contain an alternate value of B.

The Factory calibration cannot be replaced except by the Factory or Authorized Service Facilities. This involves copying and changing portions of the software which is protected by copyright.

Anyone attempting to perform the functions described in this chapter are cautioned to read and comply with the Copyright Notice contained on the inside front cover of this manual.

5.1 Measurement Systems

There is a slide switch on the circuit board of the processor Gage which instructs the processor to use one or the other of the available measurement systems. Placing the switch in the pcf position will cause all displayed data to be in these units. Placing the switch in the SI position will instruct the processor to use the International System.

This switch has no effect on variables which have no units such as percents and specific gravity. If the user is not familiar with one of the alternate systems and the displayed values seem strange, the switch is probably in the wrong position.

5.2 Calibrations Available

During the calibration procedure, the density data is reduced to an equation having three constants as explained in the theory of operation. The A and C constants are a function of the shape of the curve and the zero density intercept. The B constant is a function of the gamma attenuation coefficient of the tested material and as shipped from the factory is the average of pure limestone (Indiana) and granite (North Carolina).

The moisture data is a linear function and it is reduced to a zero density intercept and a slope. The two terms are E and F. The moisture standard is calibrated against saturated sand in a large container.

Two complete sets of these constants are available and each of them may have a additional value of B. For simplicity, the two sets of calibrations are called Factory and Field and the CONS switch is labeled FAC and FLD. The Constants switch allows the selection of either of them

Each of the sets of density constants (FAC and FLD) may be utilized with a normal and an alternate value of B. The switch is labeled BVAL and the positions are NOR and ALT. When the Gage is originally shipped to the purchaser, the same values of the constants are loaded into all of the optional space and use of the Gage will not be affected by the switch positions.

There is one additional push button switch located on the processor circuit board. It is intentionally not easily accessed by the user. The four screws holding the circuit board to the front panel must be removed and the panel folded away. Pressing this switch after pressing any one of the "RD X" keys will cause the processor to erase all user installed calibrations and alterations. The original factory calibration data will again be placed in these positions. It is available as a "fail safe" in case the user gets lost in applying the functions of altered or field calibrations or for any other reason wants to delete all of this data.

A summary of the rear panel switches follows:

SWITCH NAME	POSITIONS	FUNCTION
UNIT	SI/PCF	Select Measurement Units
CALB	USE/CAL	Select Calibration / Use Modes
CONS	FAC/FLD	Select Factory / Field Calibration

Note that NORmal and ALTernate B VALues do exist for both the FACtory and FieLD CONStants. If the FAC CONS are left in the FLD CONS memory space, another ALT BVAL can be installed, allowing two ALT BVAL for the FAC CONS.

Caution: Pressing the pushbutton switch will delete all user installed alterations and calibrations and replace them with the factory installed alterations and calibrations.

5.21 Altered Factory Calibration. The NOR value of B cannot be changed by the user. The ALT value of B can be established by means of a sample procedure and used in any situation where it is desired. An example might be aggregates consisting of slag or expanded shale where the gamma attenuation is quite different from usually available natural aggregates.

Modifying the ALT BVAL is permitted and does not require any copying or modification of the copyrighted software program which is a violation of US Copyright Laws.

The only requirement is the availability of a compacted specimen of a known density which contains these materials in the same proportion as they will be used. If only backscatter is to be altered, the specimen should be at least 375 mm (15 inches) by 600 mm (24 inches) on a smooth surface and 200 mm (8 inches) thick. If direct transmission is also to be altered, the specimen must be at least 50 mm (2 inches) deeper than the maximum depth to be altered. In addition, for direct transmission, an 18 mm (0.75 inch) vertical hole must be placed in the specimen approximately 100 mm (4 inches) from one end.

In lieu of the specimen, a field site can be established and the density determined by sand replacement. This is less desirable than using a fabricated box of known dimensions and a set of accurate scales but it can be satisfactorily used if care is exercised in the sand replacement density determination.

Set up the gage as for normal use, place it on the REFERENCE STANDARD and establish the Standard Counts using the STAT option as described in 3.2 or 6.3. This option must be used instead of the STD method of four minutes.

After the STANDARD COUNTS are established by the STAT procedure, press "FAST" to escape from the STAT procedure. Press the "RD K" key and enter a value of 0.000 in the display. Press "SHIFT" and "SET" (over "RD K") to store this value in memory.

Loosen the four thumb screws, lift up the panel and place the CALB switch in CAL and the B VAL switch in ALT. If the factory calibration is being altered, the CONS switch must be in FAC. Replace the panel.

Place the gage on the sample and position the source rod to the depth which is to have an ALT BVAL installed. The procedure may be repeated for any or all depths including backscatter which are desired.

Set the "DEPTH" display to the depth to be calibrated using the "UP/DOWN" switches. The value set must match the source rod position. An alternate B constant cannot be obtained for depth positions which were not originally calibrated.

Press the "TEST" key. "C:" will appear in the "DEPTH" display along with the indicated depth and the increasing density counts will be in the "DATA" display. After four minutes for direct transmission or 16 minutes for backscatter, "C:" will disappear and the processor will put a "d" prompt in the "DATA" display. Enter the density value using the selected units of measurement and press "SHIFT" and "SET" (over "RD D"). The processor will compute a value of B and place it in the ALT BVAL space for the FACT calibration. The "DATA" display will then indicate zeros.

If ALT BVAL constants are to be established for additional depth positions, reset the rod position and "DEPTH" setting and repeat the procedure by pressing the "TEST" key.

After all of the desired depth positions have been processed, remove the front panel and place the CALB switch in the USE position. The Gage is ready to be used for field measurements using the ALT BVAL function. The NOR BVAL may be used by simply placing the BVAL switch in the NOR position.

Both of the BVAL constants will remain in memory and can be selected by the user by use of the BVAL switch. The ALT value can be replaced by repeating this procedure, it will be replaced if the Gage is recalibrated by the factory or Authorized Service Center, and will be replaced by the FAC NOR BVAL if the pushbutton switch is pressed as noted above.

The moisture calibration is altered by using the K constant which is controlled by using the "RD K" and "SHIFT/SET" keys. The Equation to determine the proper value of K is:

$$K = \frac{\%M(oven) - \%M(gage)}{\%M(gage) + 100}$$

Oven dry or other standard tests may be used to obtain the moisture content of the material. This correction adjusts the measured content to account for hydrogen contained in the material which is not in the form of water which is removed by the oven dry.

The K factor can also be determined by making a normal measurement with the gage and adjusting K up or down until the computed %M is equal to a known value.

5.22 Field Recalibration. The Gage may be calibrated in the field by owners or their representatives rather than the Factory or other Authorized Service Facilities. This procedure does not require copying or altering the software program as prohibited by US Copyright Laws.

The procedure requires the availability of five density standards as prescribed by ASTM. They must consist of a solid magnesium block, a solid aluminum block, a block with thin alternating layers of magnesium and aluminum, a block of gray granite, and a block of limestone. The latter should be of Indiana limestone or other limestone low in magnesium oxide with a density between 2240 kg/m^3 (139.8 pcf) and 2420 kg/m^3 (151.1 pcf).

The blocks should be approximately 375 mm (15 inches) by 600 mm (24 inches) on the surface and 350 mm (14 inches) thick. If they are less than 375 mm wide, additional high density material must be added to the sides as the 5001 has a measured volume which is larger than other gages.

The laminated magnesium and aluminum standard will be approximately 700 mm (28 inches) long to allow for end plates to hold the standard together and compress the laminations.

The two solid aluminum and magnesium standards may be fabricated from thick sections of the materials bolted together.

An 19 mm (0.75 inch) vertical hole must be located about 125 mm (5 inches) from the end of the material to allow insertion of the source rod.

The density of these standards must be known to an accuracy of 0.1% or better. The method of determination is left to the discretion of the user.

5001 CALIBRATION DATA

Gage Serial Number: _____ Date: _____

Density Standard Count: _____

DENSITY DATA

	Magnesium	Magn/Alum	Aluminum	Limestone	Granite
D Value	_____	_____	_____	_____	_____
Position b					
	_____	_____	_____	_____	_____
50/ 2	_____	_____	_____	_____	_____
75/ 3	_____	_____	_____	_____	_____
100/ 4	_____	_____	_____	_____	_____
125/ 5	_____	_____	_____	_____	_____
150/ 6	_____	_____	_____	_____	_____
175/ 7	_____	_____	_____	_____	_____
200/ 8	_____	_____	_____	_____	_____
225/ 9	_____	_____	_____	_____	_____
250/10	_____	_____	_____	_____	_____
275/11	_____	_____	_____	_____	_____
300/12	_____	_____	_____	_____	_____

Moisture Standard Count: _____

MOISTURE DATA

	ALUM	M STD
M Value	0	_____
Count	_____	_____

An equivalent moisture standard having a size noted above must be available. The material used must be a hydrogenous material which will neither adsorb or absorb water from the atmosphere nor lose water due to evaporation. The equivalent moisture content should be greater than 400 kg/m^3 (25 pcf). The moisture determination should be made by comparison with a carefully constructed saturated silica sand standard of a similar size.

The solid aluminum or magnesium density standard may be used for a zero moisture content standard.

Before starting the accumulation of calibration data, the Gage should have any necessary service or adjustments made. If the batteries have not been replaced within the prior year it should be considered and if it has been two or more years they should be replaced. The bottom surface and the sliding shield cavity must be cleaned. The REFERENCE STANDARD and the calibration standards themselves must be wiped clean to assure that the surface is flat and free of foreign material.

The Gage should be turned on at least 30 minutes before the accumulation of data to allow the system to stabilize. This may be done prior to cleaning. The entire calibration should take place within one working day and this is easily accomplished by starting in the morning. The gage may be left on overnight to assure stabilization.

No other Gages must be within 10 m (33 ft) or sufficient shielding must be provided to prevent any effect on the accumulation of data. If this cannot be accomplished, or if the building background radiation is higher than the outside background, adjustments must be made. HSI can provide a background gage with no sources installed for this purpose.

The density of the calibration standards and all count rate data should be recorded on a form similar to that on page 44. This will allow the permanent retention of the data for future use in the event documentation is required.

The Gage operation is similar to field use. The Gage and REFERENCE STANDARD must be placed on one of the calibration standards and a STANDARD COUNT made using the STAT routine. This provides a very accurate count on which to base the calibration and provides a statistical stability test on the Gage.

Backscatter data will be accumulated using the STAT routine to provide the most accurate count rate determination. The gage must be centered on the standards and the base must not cover the direct transmission hole.

Direct transmission data will be accumulated using the "SLOW" MEASUREMENT key. It should be taken for all of the depth increments which are available for the gage. The DEPTH setting on the display is not important as no results need be processed. Only the "MC" and "DC" keys need be pressed to obtain the count rate data.

After the completion of the data accumulation, the Gage is ready to be programmed.

Remove the front panel and place the CALB switch in the CAL position and place the CONS switch in the FLD position. The BVAL switch must be in the NOR position if it is not already there. Replace the front panel.

Pressing "TEST" will put the Gage in the calibrate mode and a "d1" prompt will appear in the "DATA" display. This is a request for the density of the Magnesium Standard. Enter the value using the selected units of measurement and press "SHIFT" and "SET" (over "RD D"). A second prompt "d2" will appear in the display. This is repeated as follows:

Prompt	Density of
d1	Magnesium
d2	Magn/Alum
d3	Aluminum
d4	Limestone
d5	Granite

When the five densities have been entered, a prompt "Ed" will appear in the display. At this time use the "UP/DOWN" keys to set the "DEPTH" display to " b " and press "SHIFT" and "SET" (over "RD D") and a "C1" prompt will appear.

Enter the backscatter count rate from the Magnesium Standard and press "SHIFT" and "SET" (over "RD D"), a second prompt "C2" will appear in the display. This is repeated until all five count rates for the backscatter mode have been entered. After "C5" the processor will compute the A, B and C constants and store them in the proper location and "Ed" will again appear in the display to allow setting a new depth. Press the "DOWN" key to the next calibrated position and repeat this paragraph for all of the desired positions.

The field density calibration is now complete. Press "TEST" again to escape from the subroutine and put the processor back into the normal operating mode.

If a new moisture calibration is not to be installed, skip to the last paragraph.

Press "SHIFT" and "TEST" to put the processor into the moisture calibration subroutine. A "HO" prompt will appear asking for the moisture content of the standard. Enter the value and press "SHIFT" and "SET" (over "RD D"). A "C1" prompt will appear, requesting the zero moisture count and after entering it, "C2" requests the moisture count on the standard. After the last entry, new values of E and F are computed and stored in memory. Press "SHIFT" and "TEST" to leave the subroutine.

Remove the front panel and return the CALB switch to the USE position. The Gage can now be used with the field or factory calibration by moving the CONS switch between FAC and FLD.

5.23 Altered Field Calibration. The field calibration can have an alternate BVAL just as the factory calibration. In fact, if a field calibration has never been installed, this can be another alternate BVAL for the factory calibration since the factory constants are also originally stored in this location in memory.

Remove the front panel and place the CONS switch in the FLD position, the BVAL switch in the ALT position and the CALB switch in the CAL position. Replace the front panel and perform the procedure in 5.21.

When complete, the alternate B value can be used by placing the BVAL switch in the ALT position and the normal B value by using the NOR position.

Remove the front panel and place the CALB switch in the USE position and replace the panel.

5.24 Restoring the Factory Calibration. If at any time it is desirable to put the factory calibration back into the Field Recalibration and alternate BVAL memory locations, it may be quickly accomplished.

Caution. This will erase all of the other data and it will be permanently lost.

Remove the front panel and also remove the four screws which attach the printed circuit board to the panel. In the upper right portion of the circuit board there is a push button switch. With power applied to the system, press any one of the "RD X" keys. Next press the pushbutton and then press the "OFF" key. The entire field calibration will be replaced.

Reassemble the circuit board and front panel and replace the assembly in the Gage.

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

6.1 Storage Environment.

The instrument was designed to operate over an ambient temperature range of -10 to 70 °C and 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 and <u>out</u> before being put away.

6.2 Exterior Cleaning

The Gage 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 is 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 a silicon oil and the excess wiped off with a cloth. These rods are 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.

6.3 Sliding Shield Cavity

The gamma source is covered by a sliding shield of tungsten 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 Gage 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. Do not lose it when removing the shield.

Clean the parts with a wet cloth and clean the cavity with a stiff brush. Finally wipe the parts and cavity with silicon oil to help protect the finish.

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 the source and the spring compressed against the end of the cavity. 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.

6.4 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 the 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 gage in kit 5200177 and additional materials may be obtained from Humboldt or other venders 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 <u>two</u> sources in this Gage. 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 holder inside the case just forward of the main circuit board. Its location is covered by a radioactive material warning label. The edge of this label is the most accessible location to wipe.

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 Gage model and serial number, the type of radioactive material (Cs-137 and Am-241) and the source 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. Lay the Gage 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, <u>do not</u> touch the paper with fingers. Treat it as potentially radioactive material. Place the Gage in the upright position.

Remove the front panel and locate the label over the Am-241 source. Again using the tongs, wipe the edges of the label with the wetted paper. After air drying, 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 <u>and</u> authorities will be notified if the testing indicates a removable activity in excess of 5 nCi (.005 uCi) which is the legal maximum allowable. An activity in excess of 1.0 nCi will likely result in a request to rewipe the sources.

If a positive test occurs (in excess of 5 nCi) the Gage must be removed from service, decontaminated, and the source repaired or replaced before the Gage may again be used. There will be reports to file after notification of the proper authorities within 24 hours.

The leak test reports from the processor must be retained for inspection by authorities. In general, the last two reports must be kept but it is wise to keep all of them to prove compliance with regulations.

6.5 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 8.3 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, it is 433 years. The decrease in the average rate of decay for Cs-137 is 2.3% per year and for Am-241 is 0.16% per year. The effect of this change on the measurement is eliminated by calibrating the Gage in terms of a ratio.

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

$$\sigma = m^{1/2}$$

The Gage 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:

$$\sigma = \frac{m^{1/2}}{4}$$

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

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

Where: σ = Standard deviation of the count rate
n = Individual count in a set
N = Number of sets
m = Mean of the set
R = Statistical ratio

For $R>0.6$ and <1.4 Good
$R<0.5$ or >1.5 Bad
Others -- Try Again

"SHIFT/STAT" automatically runs this test and "DC" and "MC" displays the R value for the density and moisture channels.

Pressing the "RD S" key repeatedly will display the individual measurement counts if they are desired. All 16 from each test are available.

The 5001 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, 3/32 inch
Hex Key, 1/8 inch
Hex Key, 9/64 inch
Hex Key, 3/16 inch
Phillips Screwdriver, #1 X 4 inch
Slotted Screwdriver, 3/16 X 6 inch

<u>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.</u>

7.1 Mechanical Disassembly/Assembly

7.11 Bottom Plate and Shield. The Bottom Plate Assembly (4200155) is held in place by two flat head hex socket screws (1001010). Removing them will allow the plate to pull away and the Sliding Shield (2200030) and spring (1000816) can be removed for cleaning. The scraper ring (1000806) in the plate (2200033) can be replaced by removing the retaining ring (1000811).

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

Drop the source rod to the backscatter position. Remove the two hex set screws (1001007) at the top and unscrew the Lift Cap (2200051) and the Lift Bumper (2200094) 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 of 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 gage shield as soon as practical.

7.13 Indexer and Latch. This may be accomplished without removing the source rod from the Gage. Remove the Lift Cap as described in 7.12 and raise the handle off of the Index rod. Rotate the handle and push the rod back into the shield. Loosen the two hex set screws (1001034) on the sides of the handle and slide the complete latch assembly out the rear of the handle. The indexer

(2200041) will come out the slot in the side of the handle. The Index Latch Nut (2200125) may be screwed off of the Index Lock (2200126) for cleaning with silicon oil. These parts are lubricated by the teflon coating.

Remove the indexer spring (1000813) and the hex set screw (1001035) from the end of the Index Lock. Unscrew the Index Retainer (2200040) by inserting a long blade screwdriver through the Index Lock.

To reassemble, screw the retainer back into the lock, screw the nut back on the lock to the middle of the threaded section, and place the spring back over the retainer. Hold the indexer in the proper position in the handle slot and slide the latch assembly back into the handle engaging the hole in the indexer and allowing the pin in the lock to go into the groove in the handle.

Turn the knob fully clockwise and set the spacing between knob and handle at approximately 0.5 mm (0.02 inch), the padlock holes in the handle must be in alignment. Tighten the set screws in the handle to retain the latch assembly. Rotate the knob counterclockwise, press the indexer back and slide the handle down over the index rod.

To adjust the latch, place the handle in the backscatter position, turn the knob fully clockwise and while holding it, tighten the index retainer through the center of the lock firmly. With the latch released, the handle should move freely up and down the index rod.

7.14 Index Rod. The Index Rod may be removed without removing the source rod. Remove the lift cap as described in 7.12, lift the handle off the Index Rod and rotate it out of the way.

Loosen the Index Lock Nut (2200052) and unscrew the Index Rod (2200047, 48, 49 or 50) from the post. When replacing the Index Rod, latch the handle firmly in the backscatter position and screw the rod until the tip is flush to 0.05 mm (.002 inch) recessed within the bottom of the Gage. The rod must not protrude or backscatter measurements in the field could be in error.

7.15 Top Cover. First remove the processor or dual scaler module (5200115) by releasing the four thumbscrews (1001013). Lift the panel out and disconnect the Module Cable (2200105) from the base frame assembly.

Remove the six socket head cap screws (1001008) and washers (1001030) around the edge of the cover. The cover can be totally removed from the Gage by placing the handle partially between the backscatter and safe positions and working the cover over it. It will be easier if the Post Gasket (2200109) is removed from the hole.

If worn or damaged, the Shell Gasket (2200149) or Panel Gasket (2200150) should be replaced.

7.16 Top Post and Seals. Caution, the owners license must allow source rod removal before this service may be performed. With the source rod removed and safely stored as covered in 7.12 and the top cover removed, remove the six batteries from the holders. Remove the two center battery holder screws (1001016) and disconnect the Battery Cable (2200106) from the base frame assembly. Place the holders aside.

Remove the four socket head cap screws (1001009) and lock washers (1001031) from around the post. It may be lifted up over the tungsten bio shield.

The Wiper Plate (2200031) and Wiper Ring (1000803) 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 (2200032) may be removed from the Post by removing the two hex socket screws (1001007) from the side of the post. Pry up lightly on the Cap. The Wiper Ring (1000803) in the cap may be replaced by carefully prying it out of the top.

The two bearing Seals (1000805) 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 (2200136). 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 a silicon grease. Lightly coat all of the seals and wipers with the same grease before reassembling.

Reassemble in reverse order and when replacing the batteries be certain that the positive anode is in the up direction.

7.17 Base Module. After removing the Top Cover as described in 7.15, remove the batteries from the holders and disconnect the Battery Cable. There are high voltage capacitors on the circuit board which may be charged to 1000 volts. The current available is low but injury may occur due to the surprise of receiving a severe shock. Discharge them by pressing and holding the pushbutton switch at the top of the circuit board for about one minute.

Remove the seven socket head cap screws (1001008) and lock washers (1001029) around the edge of the module. Carefully lift the Base Module up out of the Gage Base. The detectors may be replaced if necessary and the parts reassembled.

This completes the description of the removal of all the major modules of the Gage.

7.2 Battery Replacement

The batteries in this Gage will last a very long time if the Gage is not stored at a high temperature. The expected service life is one to three years depending on the intensity of use. Replacement will be required within one month after the "LO BAT" symbol appears in the Display while in use.

Replacement batteries should be high quality alkaline D 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 Gage.

Remove the screws and lift the top shell sufficiently to slip the batteries out of the holders. Replace the cells with the positive terminal at the top.

7.3 Seals and Wipers

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. When the need occurs, follow the replacement instructions in 7.16.

7.4 Adjusting the Index Latch

The inner working parts of this mechanism are fully described in 7.13. These parts are extremely reliable and should never need replacing. At times some adjustment may be necessary to assure that the Latch securely locks the handle in the backscatter position.

Remove the hex head set screw from the center of the Index Lock and place the handle in the backscatter position. Insert a long slender blade screwdriver in the hole in the lock and screw the Index Retainer about one turn counterclockwise while holding the knob. Rotate the knob fully clockwise to engage the lock. Hold the knob and tightly screw the Index Retainer clockwise until the handle is firmly locked in position. When the knob is rotated counterclockwise, the handle should move freely up and down the Index rod.

7.5 Module Adjustment/Replacement

In order to improve reliability and maintain ease of service, the 5001 electronics is divided into six modules which may be individually replaced. Two of them have adjustments which may need to be set. There are two different panel modules, Dual Scaler and Processor, only one of which may be in a Gage.

7.51 Dual Scaler Module (5200115). This front panel module contains two complete counting and displaying systems and an accurate timer. Field Service is impractical other than replacement. It is easily removed by means of four thumb screws 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 recalibration is necessary and the modules are completely interchangeable between Gages.

7.52 Processor Module (5200168). This front panel module contains two counting systems, a programmed microprocessor and dual displays for depth and data. Field service is impractical other than replacement. It is easily removed by means of four thumb screws 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 recalibration is necessary; however, the Gage calibration is stored in a memory module which must stay with the same Gage or recalibration will be necessary.

7.53 Base Plane Board (5200112). 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 Gage returned. No recalibration is required.

For protection, a circuit breaker is located in the upper left corner 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.

It also has a pushbutton 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 minute before removing or replacing the High Voltage, Density, or Moisture Modules.

The entire frame, including the detectors, are 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.

7.54 Power Controller Module (5200085). This module contains a precision voltage regulator which supplies power to all of the other modules. It also contains circuits which detect a low battery voltage condition and displays this information as "LO BAT" on either of the front panel modules. The module will automatically shut down the Gage power before the battery voltage drops low enough to cause erroneous data to be taken.

It 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. No adjustments are necessary nor does the replacement affect calibration.

7.55 High Voltage Power Supply Module (5200088). This module supplies a highly regulated 1000 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 pushbutton switch located in the upper center of the base circuit board must be pushed and held for about one minute.

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. The replacement does not affect calibration.

7.56 Density Amplifier Module (5200087). This module is used to condition varying amplitude pulses from the two gamma detectors to logic level pulses for the counter in the front panel 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 pushbutton switch located in the upper center of the base circuit board must be pushed and held for about one minute.

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.

7.57 Moisture Amplifier Module (5200086). 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 pushbutton switch located in the upper center of the base circuit board must be pushed and held for about one minute.

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.

7.6 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 7.17 after discharging the high voltage.

The gamma detector(s) (2200035) 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 the Neutron Detector (2200026) out of the frame. Slide the new detector in place and carefully install the amplifier so the the module pins and the detector connector engage.

7.7 Parts List

This list includes all parts which may be field replaced.

Tool Set	
Accessory Case	5200112
Drill Rod	2200175
Scraper Plate/Rod Guide	5200130
Rod Extraction Tool	5200127
Hammer	2200145
Transit Case Assembly	1000176
Reference Standard	5200169
Gage Padlock	5200122
Instruction Manual, 5001	1000177
Radiation Safety Manual	5200167
Radioactive Source Certificate	5200121
Wipe Test Materials (Kit)	5200173
Leak Test Certificates	5200177
Filter Paper	5200174
Plastic Bags	1000175
Forceps	1000176
Lift Cap	1000181
Hex Socket SS Set Screw, 6-32 X 3/16 (2)	2200051
Lift Bumper	1001007
Index Rods	2200094
8 X 1	
8 X 2	2200047
12 X 1	2200048
12 X 2	2200049
Index Lock Nut	2200050
Handle Assembly	2200052
Gage Handle	4200120
Index Retainer	2200039
Index Lock Nut	2200040
Index Lock	2200125
Indexer	2200126
Indexer Spring, SS	2200041
Hex Socket SS Set Screw, 8-32 X 1/4 (4)	1000813
Hex Socket SS Set Screw, 1/4-28 X 3/8	1001034
Cs Source Label	1001035
Roll pin, .125 X .375	2200091
Top Cover Assembly	1001020
Top Cover	4200170
Post Gasket	2200133
Bottom Gasket	2200109
Panel Gasket	2200149
Panel Nut, 8-32 (4)	2200150
Radioactive Material Label	2200163
Hex Socket Head SS Cap Screw, 8-32 X 1/2 (6)	2200134
Flat SS Washer, #8 (6)	1001008
	1001030

Dual Scaler Module	5200115
Front Panel Assembly, Dual Scaler	4200192
Front Panel, 5001 Scaler	2200161
Display Bezel (2)	2200079
Display Gasket(2)	2200182
Captive Screw and Bushing (4)	1001013
Phillips Head SS Screw, 6-20 X 1/4 (8)	1001039
Scaler Circuit Board Assembly	4200114
LCD Display	2200110
Module Cable	2200105
Phillips Head SS Screw, 6-32 X 1/2 (4)	1001005
Processor Module (Blank Prom)	5200168
Front Panel Assembly, Processor	4200193
Front Panel, 5001 Processor	2200159
Display Bezel (2)	2200079
display Gasket (2)	2200182
Captive Screw and Bushing (4)	1001013
Phillips Head SS Screw, 6-20 X 1/4 (8)	1001039
Processor Circuit Board Assembly (Blank Prom)	4200147
LCD Display	2200110
Module Cable	2200105
Phillips Head SS Screw, 6-32 X 1/2 (4)	1001005
Battery Module (2)	4200108
Battery Holder	1000583
Battery Clip	1000432
Battery Cable	2200106
Phillips Head SS Screw, 4-40 X 3/4 (2)	1001041
Phillips Head SS Screw, 4-40 X 3/8 (4)	1001015
Post Assembly	4200154
Bearing Post	2200028
Top Wiper Cap	2200032
Wiper Ring	1000803
Hex Socket SS Set Screw, 6-32 X 3/16 (2)	1001007
Source Rod Bearing	2200136
Wiper Ring	1000803
Hex Socket Head SS Cap Screw, 1/4-20 X 1 (4)	1001009
Lock Washer, SS Split Spring, 1/4 (4)	1001031
Gage Base (No Internal Parts)	2200027
Bio Shield	2200029
Bottom Plate Assembly	4200155
Bottom Plate	2200033
Scraper Ring	1000806
Retainer Ring	1000811
Flat Head Hex Socket SS Screw, 8-32 X 1/2 (2)	1001010
Sliding Shield	2200030
Shield Spring, SS	1000816
Am:Be Source Label	2200092
Hex Socket SS Set Screw, 5/8-18 X 1/2	1001032
Base Frame Assembly	4200201
Hex Socket SS Cap Screw, 8-32 X 1/2 (7)	1001008
Lock Washer, SS Internal Tooth, #8 (7)	1001029
Base Circuit Board Assembly	5200112
Phillips Head SS Screw, 6-32 X 1/2 (5)	1001005
Lock Washer, SS Internal Tooth, #6 (5)	1001006

High Voltage Power Supply Module	5200088
Phillips Head SS Screw, 6-32 X 1 1/4	1001042
Lock Washer, SS Internal Tooth, #6	1001006
Power Controller Module	5200085
Phillips Head SS Screw, 6-32 X 3/4	1001004
Lock Washer, SS Internal Tooth, #6	1001006
Density Amplifier Module	5200087
Phillips Head SS Screw, 6-32 X 3/4	1001004
Lock Washer, SS Internal Tooth, #6	1001006
Moisture Amplifier Module	5200086
Phillips Head SS Screw, 6-32 X 3/4	1001004
Lock Washer, SS Internal Tooth, #6	1001006
Ground Spring	2200162
Phillips Head SS Screw, 4-40 X 1/4	1001014
Lock Washer, SS Internal Tooth, #4	1001018
Detector, Gamma	2200035
Detector, Neutron	5200026
Screw Set (5001)	5200178
Gasket Set (5001)	5200179
Seal and Wiper Set	5200199
Silicon Grease, General Purpose	1000174

7.8 Service Hints

No Power	Check Batteries and Circuit Breaker Replace Power Controller Replace Front Panel Module
Not Counting Anything	Replace High Voltage Power Supply Replace Front Panel Module
Not Counting Moisture	Check Pulse Voltage at MTP Replace Moisture Amplifier Replace Neutron Detector
Not Counting Density	Check Pulse Voltage at DTP Replace Density Amplifier Replace Gamma Detector
Unstable Moisture	Check Pulse Voltage at MTP Replace Moisture Amplifier Replace Neutron Detector
Unstable Density	Check Pulse Voltage at DTP Replace Density Amplifier Replace Gamma Detector(s)
Density Counts Half	Replace Density Detector
Low Unstable Counts	Replace High Voltage Power Supply
Keys don't do Function	Replace Front Module Panel
On fast keypress data display goes to 0000	Key not held long enough for processor to recognize

7.9 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 Gage base.

Users are advised to establish a location on a laboratory floor or other reference and measure this site 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 Field Calibration as covered in 5.22 then the equipment should be returned to an Authorized Service Facility or the factory.

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 the chemical elements or molecules which form the materials.

8.1 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 energy of gamma radiation, materials exposed to it are ionized and this creates a hazard to living tissue. Gamma and X radiation 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 Gage 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 .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 X 10^8 disintegrations per second. The efficiency of photon production is 85% so 3.2 X 10^8 photons are produced per second. The beta particles are absorbed by the capsule wall.

When photons 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 photon 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 Gage 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 photons will simply pass through with no interaction. The probability is a function of both the atomic number and the energy of the photon 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.

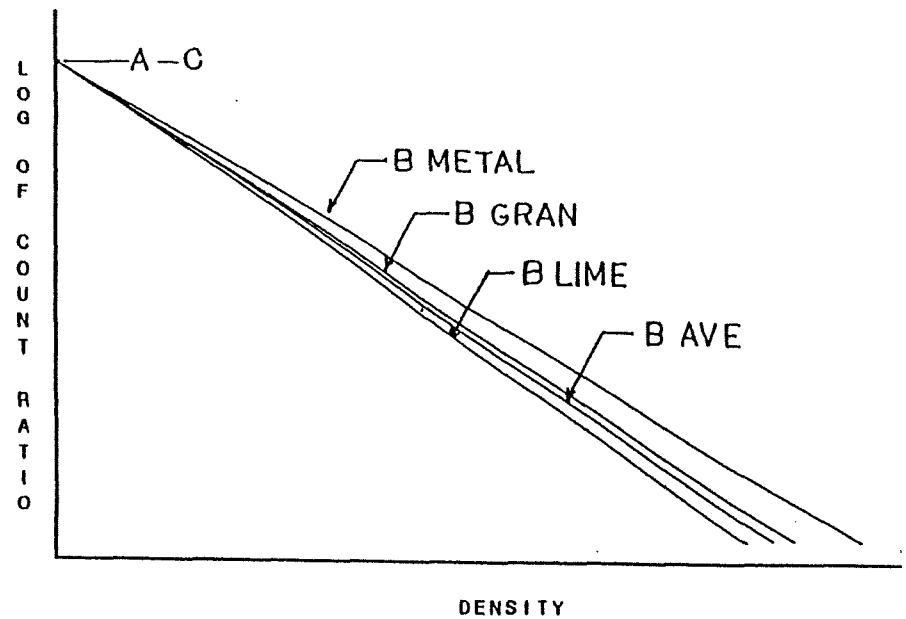
The classic equation for the attenuation of gamma passing through material is:

$$I = Io * e^{-L*p*u/p}$$

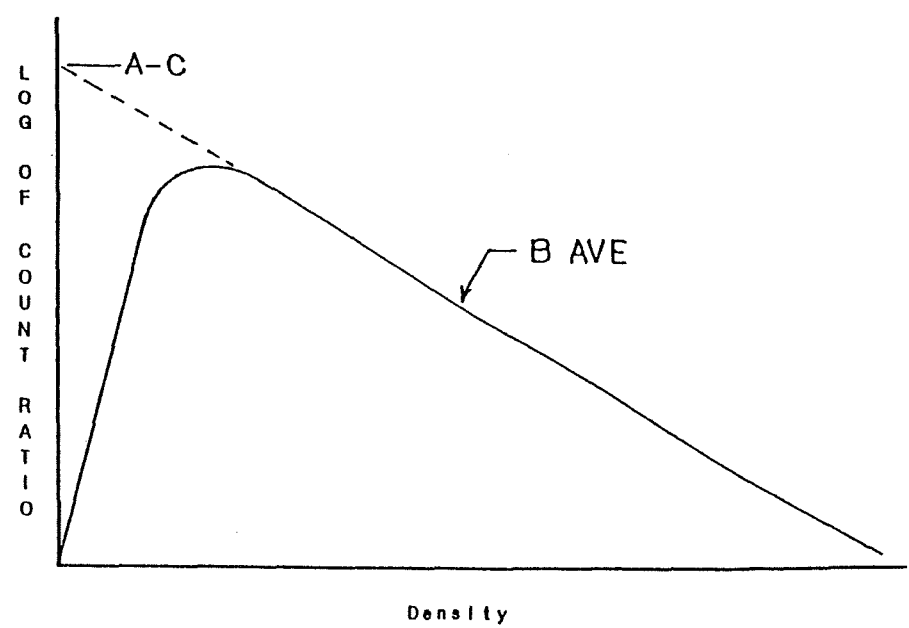
Where: I = resulting intensity
Io = initial intensity
L = path length
p = density of the material
u/p = attenuation coefficient

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(.662 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



Direct Transmission Gage Calibration



Backscatter Gage Calibration

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 gages would not be practical for use. These materials all have a u/p between 0.0805 and 0.0809. Large amounts of hydrogen in surface water does require an adjustment in the measured density.

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

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

$$CR = A*e^{-B*D} - C$$

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 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 "Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV" published by the National Bureau of Standards.

Mass Attenuation Coefficients (cm^2/g)

	PHOTON ENERGY(MeV)						
Material	0.10	0.15	0.20	0.30	0.40	0.50	0.60
Magnesium	.1610	.1360	.1220	.1060	.0944	.0861	.0796
Magn/Alum	.1620	.1350	.1210	.1040	.0931	.0849	.0784
Aluminum	.1620	.1340	.1200	.1030	.0922	.0841	.0777
Limestone	.1920	.1460	.1280	.1080	.0960	.0874	.0808
Granite	.1640	.1370	.1240	.1070	.0950	.0867	.0802
Lime/Gran	.1780	.1415	.1260	.1075	.0955	.0870	.0805
Water	.1680	.1490	.1360	.1180	.1060	.0967	.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 photon 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 ±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 photon 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 side of the material. The photon must be deflected back prior to measuring the attenuation by the 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 photons pass through the materials closest to the surface and less at deeper depths.

8.2 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 photon 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:

$$Be^{9}\ (\alpha,n)\ C^{12}$$

When the beryllium nucleus reacts with the alpha particle it emits a neutron and becomes an isotope of carbon. The C-12 is left at an excess energy state and yields a 1 to 10 MeV photon 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 X 10^4 neutrons per second along with an equal number of high energy photons.

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 neutron 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 an 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 earths crust which may either thermalize or capture thermal neutrons are listed below.

Element	Percent	Collisions	Absorption
Hydrogen	---	19	0.33
Boron	<.1	109	759.00
Carbon	<.1	121	<.01
Oxygen	44.6	159	<.01
Sodium	2.8	225	.53
Magnesium	2.1	237	.06
Aluminum	8.1	263	.23
Silicon	27.7	273	.16
Chlorine	<.1	343	33.00
Potassium	2.6	378	2.10
Calcium	3.6	387	.43
Manganese	<.1	529	13.30
Iron	5.0	537	2.53
Cadmium	<.1	1075	2390.00
Lead	<.1	1976	.17

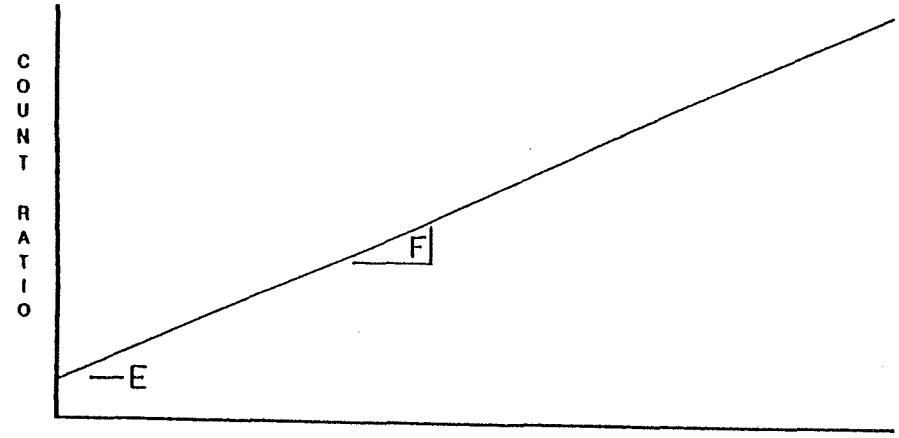
Note that the number of collisions required to produce a thermal neutron increases rapidly above hydrogen and the only other significant elements that are present, oxygen and silicon require a much larger number of collisions. Oxygen of which there is a large amount is usually uniformly distributed with 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 hydrogen. While most hydrogen in construction materials is in water, there may be hydrated minerals which contain large amounts of hydrogen and the error must be corrected.

The last 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 which 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.



Moisture Gage Calibration

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.

8.3 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 variance which is equal to the mean rate of decay.

Under these conditions, the mean of a group of samples is:

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

For N number of samples:

$$\sigma(n) = m^{1/2}$$

The range of a single sample is:

$$n = n \pm n^{1/2}$$

The standard deviation of N samples is:

$$\sigma(m) = \frac{\sigma(n)}{N^{1/2}}$$

The range of the mean is:

$$m = m \pm \frac{\sigma(n)}{N^{1/2}}$$

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

The precision of the Gage in count rate has little meaning since the purpose is to measure density or moisture content. 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.

If the calibration equation is:

$$CR = A*e^{-B*D} - C$$

or

$$n = DS*(A*e^{-B*D} - C)$$

then the differential is:

$$S = \frac{dn}{dD} = DS*A*B*e^{-B*D}$$

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 prescale value of 16 yields:

$$DP = \frac{(DS*(A*e^{-B\ D} - C))^{1/2}}{4*DS*A*B*e^{-B*D}}$$

Where: DP = Density precision
D = Density
DS = Density standard count
A,B,C = Calibration constants

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

$$MP = \frac{(MS*(E+F*M))^{1/2}}{4*MS*F}$$

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

Both of the above precisions 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 Gage should yield these values if there are no instability problems. Measurement data can be used to test the Gage. If a series of measurements are made on the same location, the values of precision can be calculated by using:

$$P = \left[\frac{\Sigma(n-m)^2}{N-1} \right]^{1/2}$$

Depending on the type of calculator used, another equation may be easier to manipulate:

$$P = \left[\frac{\Sigma n^2 - \frac{(\Sigma n)^2}{N}}{N-1} \right]^{1/2}$$

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 Gage stability. The resultant value, R, will indicate electronic noise in the circuits or an unstable detector.

The equation for this test is indicated in 6.5. The processor version of the gage has this function included in the software as described in 2.33.

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 Gage are very small amounts and only a major accident to the Gage 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.

9.1 Licensing

Prior to receipt and use of this equipment, the owner 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.

9.2 Dosimetry

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.

9.3 Leak Tests

There is a legal requirement that the sealed capsules containing the radioactive materials in this Gage must be tested for integrity of the seals. This test is described in detail in 6.4. 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.

9.4 Transport

Any equipment given to a common carrier for shipment must have a current negative leak test and the shipper must have this record in his possession along with a certification by the manufacturer that the capsule, containment system and transport container meet the US Dept. of Transportation requirements as specified in Title 49 Parts 172 and 173 of the Code of Federal Regulations. 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 Shipper's Certification for Radioactive Materials must be presented to the carrier along with the package. This certification must contain the following information.

Radioactive Material, Special Form, N.O.S.
ID# UN2974

Name	cesium-137	americium-241
Group number	III	I
Form	special form	special form
Activity	10 mCi	40 mCi

Category	YELLOW II
Transport index	0.1
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.

9.5 Disposal

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

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

9.6 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.

9.7 Radiation Profile

The maximum surface and one meter exposure rates for this equipment are listed below in mRem/h. t the time of measurement, the device contained 10.8 mCi of Cs-137 and 40 mCi of Am-241:Be with a neutron yield of 10.2 X 10^4 n/s.

The Transport Index for the Transit Case and Gage is **0.1** This value must appear on the DOT label.

	Gamma	Neutron	Total
Transit Case			
Maximum any surface	8.0	2.0	10.0
Maximum at one meter	0.08	0.02	0.10
5001 Gage			
Rear Surface	12.0	2.0	14.0
Rear at one meter	0.06	0.03	0.09
Front Surface	2.0	2.0	4.0
Front at one meter	0.03	0.03	0.06
Bottom Surface	5.0	5.0	10.0
Bottom at one meter	0.04	0.03	0.07
Top Surface	11.0	2.0	13.0
Top at one meter	0.05	0.03	0.08
Side Surface	6.0	3.0	9.0
Side at one meter	0.05	0.03	0.08
Handle	0.6	0.02	0.62
Handle at one meter	0.01	0.01	.02

The above gamma dose rates were measured on December 8, 1985 and January 23, 1986 using a Victoreen Model 471 Ionization Chamber calibrated on November 11, 1985.

The above neutron dose rates were measured and calculated on December 8, 1985 using a Victoreen Model 488A Neutron Survey Meter calibrated on June 24, 1985 and neutron dose conversion tables contained in the North Carolina Regulations for Protection Against Radiation and other regulatory documents.

WARRANTY

The purchase of this equipment includes a limited one year warranty against defective material and workmanship. Defective parts may be replaced in the field by prepaid shipment for installation by the owner.

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 EXTEND 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.

SEE COPYRIGHT NOTICE ON INSIDE FRONT COVER

Transporting Nuclear Gauges (HAZMAT)

This section provides a brief overview of the hazardous material (HAZMAT) regulatory requirements for transporting nuclear gauges. The Troxler Transportation Guide contains more detailed information, including sample shipping papers and other documentation.

The regulations governing the transportation of nuclear gauges are contained in Title 49 of the Code of Federal Regulations. Please refer to those regulations for complete details of transportation requirements. The following information summarizes some of the main requirements applicable to shippers of nuclear gauges.

Security
It is the responsibility of any person transporting a nuclear gauge to ensure that proper precautions are taken to prevent the theft of the gauge. Some commonsense suggestions and a security checklist can be found under Homeland Security on our website. To further enhance the security of gauges during transport Troxler also offers a special Mounted Transportation Box.

Certificate of Competent Authority
A copy of the IAEA Certificate of Competent Authority (sometimes referred to as "Special Form Certificate") must be on file for at least one year after the latest shipment of a nuclear gauge. You can download a copy from our web site. Please note that these certificates have expiration dates.

NOTE: The sources in some older Troxler gauges are no longer certified as Special Form because of the manufacture date. These sources may be subject to shipping restrictions or may require that you modify your shipping practices. Please refer to the Special Gauge Shipping Instructions for further details.

Type A Package Testing Results
A copy of the results of Type A package testing for the shipping case must be on file for at least one year after the latest shipment. This information can be found in the Troxler Transportation Guide.

Hazmat Training
A certificate of training must be on file for each individual who transports or prepares a nuclear gauge for transport. Troxler's Nuclear Gauge Safety Training course covers transportation requirements for nuclear gauges. Periodic Hazmat refresher training is required every 3 years.

Marking and Labeling
The package must be marked with the proper shipping name and labeled on opposite sides. Most troxler transport cases require the Yellow II label which must denote the radionuclide, activity, and

Yellow II label which must denote the radionuclide, activity, and transport index. In addition, Type A packages must be labeled "US DOT 7A Type A".

US DOT 7A Type A RQ label
US DOT 7A Type A label

Emergency Response Information
Emergency response information must accompany each shipment of a nuclear gauge. The document containing this information must be immediately accessible to the driver at all times during transportation on a public highway. A 24-hour emergency response telephone number must be listed on the shipping papers. Troxler provides this service to Troxler gauge users at no charge. The emergency response phone number is: **+1.919.549.9539**

Shipping Papers
Whenever a nuclear gauge is shipped or transported it must be accompanied by properly completed shipping papers. Please consult the Troxler Transportation Guide for details. When transported via highway a properly completed bill of lading must be in the transport vehicle and immediately accessible to the driver.

Sealing of Package
Each Type A package must contain a seal that is not readily breakable and provides evidence that the package has not been opened in transit. This seal is required when transporting a gauge to and from a work site, as well as when shipping the gauge by a common carrier (e.g. FedEx).

Inspection Prior to Shipment
Before transporting a nuclear gauge, the shipper must inspect the package (shipping case) to ensure it is in good physical condition other than superficial marks and that all closure devices are in good working order and secured.

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Radiation Safety Primer

Introduction
Radiation is an extraordinarily versatile and useful tool in medicine, industry, and research. It helps saves lives and provides great benefits to mankind in innumerable ways. Radiation is no different than other tools. If used improperly it can be hazardous to health or cause injury. But, if proper precautions are followed radiation can be used safely to achieve superior results. We will briefly introduce some basic radiation safety concepts and principles as they apply to the use of portable nuclear gauges. While the human body can sense and take actions to prevent injury by many physical agents, such as heat and noise, it cannot sense radiation. Therefore, it is important to understand the nature of radiation, its sources, and how to protect yourself and others.

A Brief History
In 1895, a German physicist named Wilhelm Roentgen fortuitously discovered X-rays while experimenting with evacuated glass tubes through which an electric current was passed. Roentgen discovered he could take a picture of the bones in his hand with the mysterious new rays. Henri Becquerel of France discovered natural radioactivity a year later. In 1898, Pierre and Marie Curie isolated the first radioactive elements, radium-226 and polonium-210. The momentous discoveries of these physicists led to a rapid advancement of scientific knowledge about radiation and radioactivity, as well as to many practical uses.

Types of Radiation
For purposes of radiation safety only radiation with the capability to cause ionization is of concern. Ionization occurs when electrons are dislodged from a neutral atom. When this happens an atom becomes positively charged and some energy is transferred. Ionization is the process by which radiation affects the human body and by which it can be detected as well. There are four basic types of ionizing radiation: alpha, beta, gamma and neutron. The main properties of each type of radiation are briefly discussed below.

Alpha particles consist of two protons and two neutrons and carry a positive charge. They are emitted with high energy from the nucleus of heavy elements during radioactive decay, but lose energy rapidly in passing through material. A couple sheets of paper are sufficient to stop most alpha particles. Since they cannot penetrate even the outer dead layer of our skin, they are not an external hazard.

Beta particles are electrons emitted from nucleus of atoms at nearly the speed of light. They have a very small mass compared to protons or neutrons and carry a negative charge. Very energetic beta particles can penetrate 1/2 inch of wood.

Gamma rays are electromagnetic energy waves emitted from the nucleus of atoms and have no charge. X-rays are the same as gamma rays, except they originate outside the nucleus from processes involving electrons. Other familiar types of electromagnetic wave radiation include: visible light, ultraviolet light, infrared light, microwaves, and radiowaves. These differ from X-rays and gamma rays only in wave frequency and energy. Gamma rays are much more penetrating than alpha or beta particles.

Neutrons are elementary particles which are emitted during certain types of nuclear reactions. Neutrons have no charge and are also highly penetrating.

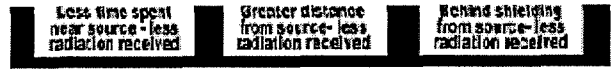
Units of Measure for Radiation
The primary quantity of interest in radiation protection is dose equivalent. It so happens that some types of radiation produce greater effects on the body than others for the same amount of energy absorbed (absorbed dose). To account for this, a Quality Factor (QF) is assigned to each type of radiation to express its relative effectiveness in producing damage. Dose equivalent is the product of the absorbed dose and the QF for that type of radiation. It expresses the risk of harm resulting from exposure to different types of radiation on a common scale. The basic unit of dose equivalent is the rem. Because a rem is relatively large amount, the millirem (1/1000 of a rem) is often used instead.

Natural Sources of Radiation
Radiation is emitted by radioactive elements naturally present in the soil, water, and air. The major sources include potassium-40, uranium-238, and thorium-232. By virtue of their presence in the environment, radionuclides are found all the way up the food chain to humans. The human body contains a number of radioactive elements, including potassium-40, radium-226, and carbon-14. Building materials, like granite, contain radioactive thorium-232. Even the air we breathe contains small concentrations of the radioactive gas, radon-222, which seeps from the Earth's crust. Cosmic rays from outer space are another significant natural source of radiation. The atmosphere screens out most of the cosmic rays, but some still penetrate to ground level. The dose from cosmic rays increases with altitude. For example, people living in mile-high Denver receive about twice as much dose from cosmic rays as people living at sea level. The interaction of cosmic rays with nitrogen in the atmosphere also produces radioactive carbon-14 and tritium (H-3).

Man Made Sources of Radiation
Manmade radiation is produced directly through the operation of devices like X-ray machines, particle accelerators, and nuclear reactors. Accelerators and nuclear reactors may also produce manmade radioactive elements that emit radiation. Many manmade nuclides are used in medicine, industry, and research. For example, moisture-density gauges use the manmade sources: cesium-137 (gamma source), Cf-252 (neutron source), and americium-241:beryllium (neutron source).

Uses of Radiation and Radioactive Materials
Radiation and radioactive materials have many uses in medicine, industry, education, agriculture, consumer products, scientific research, and many other fields. Here is a partial list of current uses:

•	medical imaging for disease diagnosis	•	disease treatment
•	lightning rods	•	material composition determination
•	f low detection	•	smoke detection
•	medical instrument and food	•	well logging



Time:
The most direct way to reduce radiation dose is to reduce the time spent working with or in the vicinity of radiation sources. If the exposure time is cut in half, the dose will be reduced by the same fraction.

Distance:
Distance is one of the most effective means to reduce dose thanks to basic principles of geometry. When the working distance from a point radiation source is increased by a factor of two, the dose received from that source will be reduced by a factor of four. This is referred to as the inverse square law, i.e., the radiation intensity from a point source decreases with the square of the distance from the source.

Shielding:
Shielding is any material used to reduce the intensity of radiation by absorbing or attenuating the radiation coming from the source. Nuclear gauges have a significant amount of shielding already built in to protect the operator.

Further information about radiation and radiation safety can be found at a number of sites on the world wide web.

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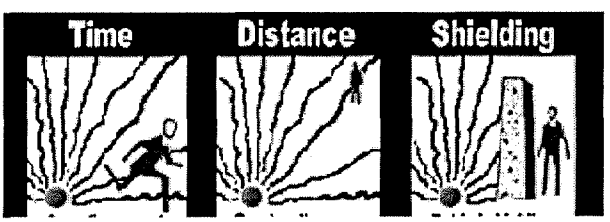
•	medical instrument and food sterilization	•	well logging
•	radiocarbon dating	•	radiotracer studies
•	anti-static devices	•	gemstone coloration
•	vulcanization, cross-linking	•	deep space power source
•	weapon detection, baggage scanning	•	reactor fuel
•	bomb detection	•	emergency exit signs
•	airport runway lights	•	spark gap tubes or glow lamps
•	spark gap irradiators	•	timepiece, instrument, and gunsight lighting
•	physical property measurement (thickness, moisture, density)		

How Radiation Affects People
Radiation causes ionization in the molecules of living cells. The ions react with other atoms in the cell causing damage that interferes with vital cell processes and with cell reproduction. At low doses, such as we receive from natural background radiation, the cell may be able to repair the damage with no adverse effect. At higher doses, the cells might not be able to repair the damage and the cells die or may reproduce abnormal cells that become cancerous. The primary risk from occupational exposure to radiation is a slightly increased risk of developing cancer. Several factors influence how much effect a given radiation dose will have on living cells.

- All cells are not equally sensitive to radiation. Cells that divide rapidly, like blood cells and the lining of the GI tract, are more susceptible to damage than cells that divide slowly, like nerve and brain cells.
- Dose to the whole body dose carries greater risk than dose to a portion of the body.
- A given dose received over long time period (years) is less likely to cause an effect than the same dose received over a short time period (hours).

Radiation Dose Limits
The federal government has set standards for how much radiation can be received safely. The limit for whole body radiation for persons working in occupations that involve radiation exposure is 5000 millirem per year. To put this value in perspective, the average American receives about 360 mrem a year from natural background radiation.

Protection from Radiation Sources
The radioactive material in portable gauges is in the form of sealed sources, therefore, there is negligible chance of internal exposure or contamination from working with a nuclear gauge. The primary concern is external exposure. The fundamental principle in radiation protection is that all radiation exposures should be maintained as low as reasonably achievable. This is referred to as the ALARA principle. The three key factors which influence an individual's radiation dose from a given source are time, distance and shielding. Control of these factors, therefore, is the key to keeping radiation dose ALARA.



Emergency Procedures

These emergency instructions apply whenever a nuclear gauge is involved in an event that might cause damage to the source or its shielding or prevent the return of the source to the shielded position (e.g. when the gauge is struck by a piece of equipment, is contained in a vehicle involved in an accident or involved in a fire).

Gauge User or Operator:
Immediately cordon off the area around the gauge (approximately 15 foot radius) and prevent unauthorized personnel from entering the area to minimize personnel exposure. The gauge operator should stand by outside the cordoned area and maintain constant surveillance of the gauge until emergency response personnel arrive.

Detain any equipment or vehicle involved in the accident and the operator until it is determined that no contamination is present. Gauge users and other potentially contaminated personnel should not leave the scene until they have been checked for contamination by emergency response personnel.

Notify appropriate emergecy response personnel (e.g. the licensee's Radiation Safety Officer, NRC or State officials) as soon as possible.

RSO and Licensee Management:
Evaluate the condition of the gauge. Determine if the source(s) are present and if they are in the shielded position (if applicable). If the source(s) are out of the gauge they must be located immediately.

Arrange for a radiation survey to be conducted as soon as possible by a knowledgeable person using appropriate radiation detection instrumentation. This person could be a licensee employee or a consultant competent in the use of radiation survey meters. The Troxler gauge operation manual contains a radiation profile chart which gives the normal radiation levels near the gauge. The radiation survey readings can be compared to the radiation profile for the gauge contained in the gauge operation manual to determine if the readings are normal.

Make necessary notifications to local authorities as well as the NRC as required. Even if not required to do so, you may report any incident to the NRC by calling NRC's Emergency Operations Center at 1.301.816.5100, which is staffed 24 hours a day and accepts collect calls. NRC or Agreement State notification is required when gauges containing licensed material are lost or stolen, when gauges are damaged or involved in incidents that result in doses in excess of 10 CFR 20.2203 limits, and when it becomes apparent that attempts to recover a source stuck below the surface will be unsuccessful. NRC reporting requirements and timeframes are found in 10 CFR 20.2201-2203.

Returning Damaged Gauges to Troxler
When it is necessary to return a gauge that has been damaged to Troxler for repair or disposal, the following procedure must be followed.

Conduct a standard wipe test of the gauge to verify the sources are not leaking and provide the test results to Troxler.

Send photographs showing the damage, especially damage affecting the shieldling of the radioactive sources, to the attention of the Troxler RSO. If the damage is extensive or the gauge cannot be shipped in the original shipping case, Troxler will provide assistance or directions for packaging and shipment.

Upon review of the leak test results and photographs by the Troxler RSO, a Returned Goods Authorization (RGA) number will be issued for return of the gauge to Troxler.

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TROXLER TRANSPORTATION GUIDE

This guide applies to transportation of Troxler nuclear gauges in the United States.

Revision 28
(June 2007)

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The Leader in Construction Testing Equipment

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PN 106978
June 2007
Revision 28

TRANSPORTATION GUIDE

OVERVIEW AND APPLICABILITY

This guide is designed to assist Troxler nuclear gauge users in complying with U.S. Department of Transportation (DOT) hazardous material (hazmat) regulations and International Air Transport Association (IATA) Dangerous Goods Regulations. It highlights and explains the major requirements for shipping and transporting portable nuclear gauges in the U.S.

Troxler recommends that persons shipping and transporting nuclear gauges obtain and read the applicable DOT and IATA regulations. The U.S. DOT regulations are published in Title 49 of the Code of Federal Regulations, Parts 100-185 (49 CFR 100-185), which can be viewed online at the U.S. DOT hazmat web site: http://hazmat.dot.gov. IATA Dangerous Goods Regulations may be purchased from the IATA online store at: http://www.iata.org.

The U.S. DOT HAZMAT regulations apply to all U.S. domestic shipments by all modes of transport. IATA regulations apply to all shipments by air, both international and domestic. When shipping a nuclear gauge by Federal Express®, the gauge must be prepared in accordance with IATA regulations for shipment by air. Throughout this guide, you will see references to the applicable sections of the U.S. DOT regulations given in brackets, such as [§173.410].

The focus of this guide is on preparing nuclear gauges for shipment via common carriers and on transporting gauges as a private carrier. Private carriers generally own the goods (nuclear gauge) being transported and the transportation of the goods is incidental to their regular business activity. A company that owns a nuclear gauge and transports it to and from job sites in the course of business is considered a private carrier. Common and contract carriers, on the other hand, are "for hire" carriers whose primary business is transportation of goods for others.

The major requirements that apply to shipping a gauge via common carrier or transporting a gauge as private carrier include:

- A current copy of the International Atomic Energy Agency (IAEA) Certificate of Competent Authority (special form certificate) for each source in the gauge must be on file.
- The gauge must be in a TYPE A package and a copy of the TYPE A package testing results must be on file.
- The package must be properly marked, labeled, sealed, and inspected prior to each shipment.
- The package must be properly loaded and secured in the vehicle.
- Properly completed shipping papers (bill of lading) must be in the transport vehicle and immediately accessible to the driver
- An Emergency Response Information document must be in the transport vehicle with the shipping papers and immediately accessible to the driver
- An emergency response phone number must be manned continuously while the gauge is in transit (this service is provided free of charge by Troxler)
- A certificate of training must be on file for each hazmat employee involved in the shipment, essentially any individual involved in packaging, preparing shipping papers, or transporting a nuclear gauge (training classes are offered by Troxler)

TRAINING

If you own portable nuclear gauges, HAZMAT training is critical to your business. According to the U.S. DOT Office of Hazardous Material Safety:

> *"More than one-third of the Department's enforcement actions pertaining to violations of the hazardous materials transportation regulations involve the failure of hazmat employers to provide training or maintain test records. In most cases, violations are attributed to failure to provide function specific training. For example, an investigator questions incorrect entries on a shipping paper prepared by a hazmat employee who responds that he was not instructed, nor tested, by his hazmat employer regarding the preparation of shipping papers."*

The regulations define a *hazmat employee* as a person (including a self-employed person) who is employed by a hazmat employer and who:

- Loads, unloads, or handles hazmat (e.g., a nuclear gauge);
- Tests, reconditions, repairs, modifies, marks, or otherwise represents packagings as qualified for use in the transportation of hazmat;
- Prepares hazmat for transportation;
- Is responsible for safety of transporting hazmat; or
- Operates a vehicle used to transport hazardous materials.

Each hazmat employer must train and test, certify, and develop and retain records of current training for each hazmat employee (during the period of employment and 90 days thereafter).

Initial hazmat training must be completed within 90 days of employment or change in job function. Before completing training, an employee may only perform hazmat functions under the direct supervision of a properly trained and knowledgeable hazmat employee.

Recurrent training is required at least once every **three years** per U.S. DOT rules.

Relevant training received from a previous employer or source may be used to satisfy the requirements provided a current record of training is obtained from the previous employer or source.

Hazmat employee training must include the following:

- General awareness/familiarization training
- Function-specific training
- Safety training
- Security awareness training

Training records must include:

- Hazmat employee's name;
- Completion date of most recent training;
- Training Materials (copy, description, or location);
- Name and address of hazmat trainer; and
- Certification that the hazmat employee has been trained and tested.

To assist you in meeting these training requirements, Troxler offers both initial and refresher hazmat training courses, including testing and certification. For further information about Troxler training opportunities, please consult our website: http://www.troxlerlabs.com.

CERTIFICATE OF COMPETENT AUTHORITY

The sealed sources in Troxler gauges meet the U.S. DOT requirements for classification as Special Form Radioactive Material. Special Form materials are designed and constructed to maintain their physical integrity even under severe accident conditions. For all practical purposes, such materials cannot produce radioactive contamination. The testing requirements that "special form" materials must meet are described in §173.469. Sources meeting these requirements are issued a Certificate of Competent Authority by the International Atomic Energy Agency (IAEA).

A shipper must keep a copy of the IAEA Certificate of Competent Authority (also known as Special Form Certificate) for at least one year after the latest shipment of special form radioactive material [§173.476(a)]. An example of a special form certificate is shown in Appendix F. Please note that these certificates have expiration dates. You must have a current copy in your possession before you can legally ship special form radioactive materials. If shipping a gauge by air, a copy of the special form certificate must be included with the shipment.

Current copies of the certificates can be downloaded from the Troxler web site (www.troxlerlabs.com) or requested by calling Troxler. When requesting a special form certificate, please provide your gauge model number and serial number or the special form certificate number. You can determine the applicable special form certificate numbers by referring to the Troxler gauge certificate.

NOTE

Troxler issues a "gauge certificate" with each gauge. This certificate is sometimes confused with the special form certificate described above. The Troxler gauge certificate gives the gauge model and serial number, owner name and address, and information about the sources in the gauge, including the special form certificate number. The Troxler gauge certificate is not a legally required document for purposes of shipment. However, it is useful when being inspected by either your licensing agency or U.S. DOT, since it provides relevant gauge information.

TYPE A PACKAGES

The type, form, and quantity of radioactive material in most Troxler nuclear gauges requires the use of Type A packaging during transportation. The Troxler gauge shipping case meets all Type A package standards. [§173.410 and §173.412]

Each shipper of a (Specification 7A) Type A package must maintain on file for at least one year after the latest shipment, documentation of the Type A package testing methods and results. This documentation is provided in Appendix A for all Troxler gauges/cases currently manufactured. [§173.415(a)]

MARKING TYPE A PACKAGES

Each Specification 7A package (Troxler shipping case) must be marked on the outside "U.S.A. DOT 7A TYPE A" and "RADIOACTIVE MATERIAL." [§178.350(b)]

Each package must be marked with the proper shipping name and United Nations identification number (UN ID). [§172.301(a) and (c)]

The U.S. Environmental Protection Agency (EPA) requires notification of serious accidents involving certain quantities of hazardous substances. These "Reportable Quantities" must be identified by the abbreviation "RQ". For Troxler gauges containing 10 mCi or more of Americium-241 or Americium-241:Beryllium, the letters "RQ" must be marked on the package next to the proper shipping name. [§172.324(b)]

All of the above marking requirements are incorporated into a single label on each Troxler shipping case.

U.S. DOT requires the consignee's (receiver) or consignor's (transferor) name and address to be marked on the package, except when the package is transported by highway only and will not be transferred from one motor carrier to another. Therefore, when transporting a gauge to and from a job site by highway, name and address marking is not required. However, if a gauge is transported by a common carrier, name and address marking is required. [§172.301(d)]

LABELING TYPE A PACKAGES

Type A packages containing nuclear gauges are required to have RADIOACTIVE YELLOW-II hazard labels affixed to opposite sides (not top or bottom) near the proper shipping name marking. The following information must be entered on the labels in legible printing with a durable weather-resistant means of marking [§172.403(g)]:

- **Contents** – the name of the radionuclide(s) in the package (e.g., Cs-137 and Am-241:Be)
- **Activity** – the activity of the radioactive materials expressed in appropriate SI units, e.g., megabecquerels (MBq), gigabecquerels (GBq).
- **Transport Index** (for YELLOW-II or YELLOW-III labels only) – the maximum radiation level at one meter from the surface of the package in millirem/hour. See Appendix G for a list of TI values for Troxler gauges.

Type A packages containing nuclear gauges are not allowed on passenger-carrying aircraft. When offered for transport by air, including Federal Express, nuclear gauge packages must bear a CARGO AIRCRAFT ONLY label. [§173.448(f), §172.402(c)]

SECURITY SEALS

Each Type A package must incorporate a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened. The seal is required when transporting a gauge to or from a work site, as well as when shipping a gauge via common carrier. You should also lock the gauge before placing it in the case. [§173.412]

INSPECTING PACKAGE BEFORE SHIPMENT

The shipper must inspect each package (gauge shipping case) before each shipment to ensure it is in unimpaired physical condition, except for superficial marks, and that each closure device (hinge, hasp, latch, etc.) is properly installed, secured, and free of defects. [§173.475]

The shipper must also ensure that external radiation and contamination levels are within allowable limits and are consistent with the Transport Index shown on the radioactive labels on the package. If the gauge is in undamaged condition, this requirement may be met by visual inspection of the gauge. However, if the gauge has been damaged then radiation measurements should be made with a survey instrument and a leak test performed on the sealed sources prior to shipping or transporting the gauge.

WARNING

Do not ship or transport a gauge with a sliding block that is not fully closed.

SECURING PACKAGES IN VEHICLE

Any package of radioactive material must be secured against movement within the transport vehicle under conditions normally incident to transportation. [§177.834(a) and §173.448]

MINIMUM SEPARATION BETWEEN PACKAGES AND PEOPLE

Packages bearing RADIOACTIVE YELLOW-II or YELLOW-III labels are not to be carried in compartments occupied by passengers. These packages must be kept a minimum distance away from vehicle occupants, based on the transport index, as shown in the table below. If more than one package is present, the distance (measured from the nearest point on any package) must be based on the total transport index for all of the packages. [§177.842(b)]

Total Transport Index	Minimum Distance (Feet)
0.1 to 1.0	1
1.1 to 5.0	2
5.1 to 10.0	3
10.1 to 20.0	4
20.1 to 30.0	5
30.1 to 40.0	6
40.1 to 50.0	7

For example, a Troxler 3440 gauge with a TI of 0.6 must be kept at least 1 foot away from the driver or passengers. Two Troxler 3440s with a combined TI of 1.2 must be kept at least 2 feet from the driver or passengers.

SHIPPING PAPER PREPARATION AND RETENTION

Shipping paper examples are shown in Appendices B, C, D, and E. Shipping papers must include:

- UN identification number: UN 3332
- Proper shipping name: "Radioactive material, Type A package, special form"
- Hazard class: 7
- The letters "RQ" for reportable quantities of material if package contains 10 mCi or more of Am-241
- Radionuclide names: See Appendix G to determine nuclides for your gauge
- Activity: See Appendix G to determine activities for your gauge
- Label category: Radioactive Yellow-II
- Transport index (dose rate in mrem per hour at 1 meter): See Appendix G to determine TI for your gauge
- The words "Cargo Aircraft Only" if the package is offered for transport by air
- Emergency telephone number: 919-549-9539
- Date of acceptance by carrier (i.e., the shipment date)

Shippers and carriers must retain a copy of the shipping papers, or an electronic image thereof, for a period of 2 years after the date the hazardous material is accepted by a carrier. An electronic image includes an image transmitted by fax machine, an image on the screen of a computer, or an image generated by an optical imaging machine. The copy (paper or electronic) must be accessible at or through the principal place of business and immediately available upon request by an authorized official of federal, state, or local government. [§172.201(e)]

Private carriers who use the same shipping paper for multiple shipments of the same hazardous material may retain a single copy of the permanent shipping paper, instead of a copy for each shipment made, if the carrier also retains a separate record of each shipment made, including:

- Shipping name (proper shipping name)
- Identification number (UN identification number)
- Quantity transported (activity in the shipment)
- Date of shipment

SHIPPER'S CERTIFICATION

For any shipment offered for transport by common carrier, the shipping papers must include a signed and dated shipper's certification statement:

> *"This is to certify that the above-mentioned materials are properly classified, described, packaged, marked, and labeled, and are in proper condition for transportation according to the applicable regulations of the Department of Transportation."*

For transportation by air, the following statement must be added to the above certification:

> *"I declare that all of the applicable air transport requirements have been met."*

No certification is required for a hazardous material transported by motor vehicle by a private carrier if the material will not be reshipped or transferred to another carrier (i.e., no certification is required when a gauge is transferred to and from a job site in a Company vehicle). [§177.204]

SHIPPING PAPER ACCESSIBILITY

When transporting hazmat by motor vehicle, the driver must ensure that the shipping papers are readily available to, and recognizable by, authorities in the event of an accident or inspection. The shipping paper must be clearly distinguished, if it is carried with any other papers, by either tabbing it or by having it appear first in the stack of papers.

When the driver is at the vehicle's controls, the shipping paper must be within immediate reach while the driver is restrained by the lap belt. The paper must be either readily visible to a person entering the driver's compartment (e.g., on the seat next to the driver) or in a holder which is mounted to the inside of the door on the driver's side of the vehicle.

When the driver is not at the controls of the vehicle, the shipping papers must be on the driver's seat or in a holder which is mounted to the inside of the door on the driver's side of the vehicle. [§177.817(e)]

EMERGENCY RESPONSE INFORMATION

An emergency response information sheet must accompany the shipment of a nuclear gauge. This document must be in the transport vehicle and immediately accessible to the driver during transportation on a public highway. Troxler includes a copy of this document with each gauge. An example of an emergency response information sheet is shown in Appendix E. [§172, Subpart G]

EMERGENCY RESPONSE PHONE NUMBER

A 24-hour emergency response telephone number must be provided on the shipping paper. This number must be manned continuously, while the gauge is in transit, by someone who is knowledgeable of the hazards and characteristics of the hazardous material being shipped, has comprehensive emergency response and accident mitigation information for that material, or has immediate access to a person who possesses such knowledge and information. Troxler currently provides this service to Troxler gauge users at no charge **(919-549-9539).** [§172, Subpart G]

ACCIDENT NOTIFICATION REQUIREMENTS

Notify your licensing agency as soon as practical after a reportable incident. You are also required by §171.15 to notify, at the earliest practical moment, the **U.S. DOT at 1-800-424-8802** of an accident that occurs during the course of transportation (including loading, unloading, and temporary storage) in which fire, breakage, spillage, or suspected contamination occurs involving shipment of radioactive material.

EXCEPTED PACKAGES

Some Troxler nuclear gauges may be shipped as excepted packages, including Models 3660, 4301, and 4302. Excepted Packages are not subject to the specification packaging, marking, labeling and shipping paper requirements described above for Type A packages. Excepted packages are subject to the following requirements:

- The outside of the package must show the full name and address of the shipper and consignee.
- The outside of the package must be marked with the UN ID number: "UN 2911"
- For shipment by air, the package must be must be labeled with the Radioactive Material, Excepted Package label. (IATA 10.7.4.4.3)
- For shipment by air, the air waybill must state in the "Nature and Quantity of Goods" box "Radioactive material, excepted package, instruments, UN 2911", however, a Shipper's Declaration for Dangerous Goods form is not required. (IATA 10.8.8.3)

Shippers and carriers of excepted packages are still subject to the hazmat employee training requirements and accident notification requirements of the hazardous material regulations.

APPENDIX A

TESTING RESULTS FOR TYPE A PACKAGES FOR TROXLER GAUGE CASES

INSTRUCTIONS FOR FINDING TYPE A TESTING RESULTS FOR YOUR PACKAGE:

1. Determine your shipping case type by using the drawing below.
2. Find your gauge model number in the first column of the table on the next page.
3. Find the corresponding case in the second column of this row.
4. Gauges that are no longer in production may not be listed. Please contact your Troxler representative or the Troxler corporate headquarters if you need assistance.

TESTING PERFORMED & RESULTS (unless otherwise indicated in footnotes):

Water Spray: Subjected the package to a water spray simulating rainfall of approximately two inches per hour for one continuous hour.
Results: No physical damage to the package was observed, unless otherwise noted in footnotes.

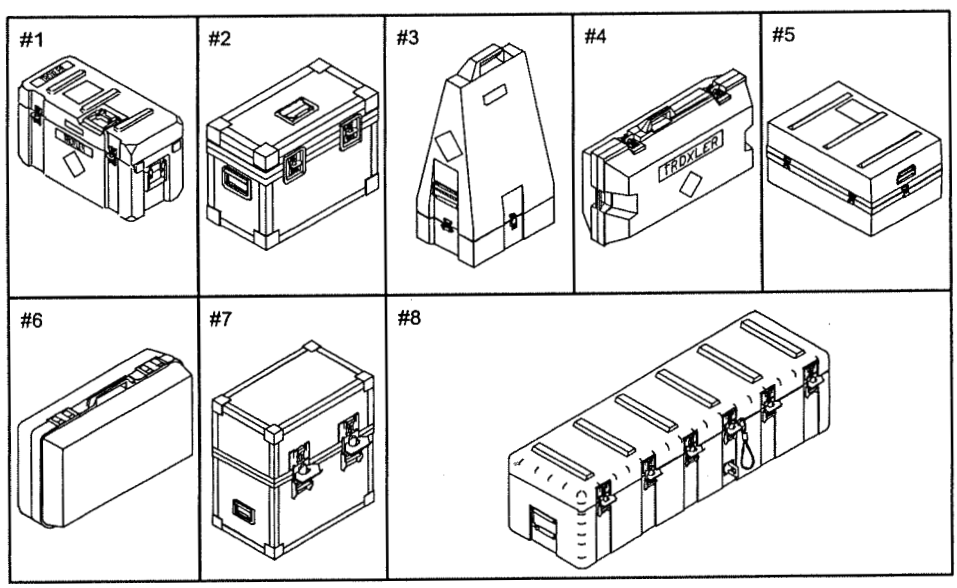
Vibration: The package was vibrated with a displacement of 0.1" at approximately 12 Hz for a period of 24 continuous hours.
Results: No physical damage to the package was observed, unless otherwise noted in footnotes.

Free Drop: The package was dropped from a height of four feet onto a non-yielding surface from a position to cause maximum damage to the package.
Results: The case was scratched due to the abrasiveness of the concrete, but no other physical damage to the package was observed, unless otherwise noted in footnotes.

Penetration: The package was placed on a non-yielding surface. A 1-1/4" diameter, 13-pound steel cylinder with a hemispherical end was dropped in the vertical position from a height of 40" onto the package to a point to cause maximum damage to the package.
Results: No physical damage to the package was observed, unless otherwise noted in footnotes.

Compression: Package was placed on a non-yielding surface and subjected to a compressive load of at least 13 kilopascals multiplied by the vertically projected area of the package, in square feet, for 24 continuous hours.
Results: No physical damage to the package was observed, unless otherwise noted in footnotes.

PACKAGE DRAWINGS:



RESULTS OF TESTING

Consult the table below for applicable testing results, as described in the instructions on the previous page. A [✓] in the table below indicates that the applicable test was performed. The results are on the previous page of this document unless otherwise stated in the referenced footnotes.

GAUGE MODEL	CASE/ DRAWING #	WATER SPRAY	VIBRATION	FREE DROP	PENETRATION	COMPRESSION	PACKAGE WEIGHT (lbs)	DATE TEST COMPLETED
3241 SERIES- 3241-A, 3241-B 3241-C, 3241-M 3242	WATER RES/#1	(1)	✓	✓	✓	✓	103, (5)	9/91
	GAUGE ONLY	(1)	✓	✓, (3)	✓, (3)	✓, (2)	55	1/83
3216, 3217, 3218, 3221, 3222	PYRAMID/#3	(1)	✓	✓	✓	✓, (7)	93, (5)	9/91
	PLASTIC/#6	(1)	✓	✓	✓	✓	70, (5)	6/91
3400 SERIES- 3401, 3401-B 3411, 3411-B 3430, 3430-M 3440, 3440-M, 3440-L	WATER RES/#1	(1)	✓	✓	✓	✓	110, (5)	9/91
	TRUNK/#2	(1)	✓	✓	✓	✓	115, (5)	9/91
	PYRAMID/#3	(1)	✓	✓	✓	✓, (7)	93, (5)	9/91
	BLOWMOLD/#4	(1)	✓	✓	✓	✓, (2)	81	5/85
	ABS/#5	(1)	✓	✓	✓	✓	105, (5)	9/91
3430 Plus, 3440 Plus	WATER RES/#1	(1)	✓, (10)	✓	✓	✓	83	1/07
3450, 3451	WATER RES/#1	(1)	✓	✓	✓	✓	96	7/96
4232	WATER RES/#1	(1)	✓, (8)	✓	✓	✓	70, (9)	1/95
4350	WATER RES/#8	(1)	✓	✓	✓	✓	122	3/92
4430	TRUNK/#7	(1)	✓	✓, (3)	✓	✓	107	12/92
4440 SERIES	WATER RES/#1	(1)	✓	✓	✓	✓	120, (5)	9/91
4640	WATER RES/#1	(1)	✓	✓	✓	✓	110, (5)	8/96
	TRUNK/#2	(1)	✓	✓	✓	✓, (2)	93	6/84

Notes:

1. Engineering Evaluation – Water exposure of the magnitude required by regulations would not affect the shielding or containment integrity.
2. Compressive load at date of test was specified as being derived using the "maximum horizontal cross-section of the package," in place of the "vertically projected area of the package."
3. Cosmetic damage was observed.
4. Package material was exempt from this test per regulations at the time of testing.
5. Package tested with full weight plus 20 pounds added.
6. Package weight not available (case is no longer in production).
7. Engineering Evaluation - Test not practical due to case geometry.
8. The case was vibrated with a displacement of 1/8" at 15 Hz for a period of 24 continuous hours.
9. The weight of the case and dummy contents as tested was 74 lbs.
10. Engineering Evaluation – Package design and construction are equivalent to other packages in use which have had no vibration-related failures.

Test results were obtained from the most current Type A package testing and evaluation documentation.

APPENDIX B

PRIVATE CARRIER BILL OF LADING FOR A 3400 SERIES GAUGE

This example shows a bill of lading for a 3400 Series gauge transported by private carrier. This document is NOT required to be dated. However, the carrier must retain a record of each shipment made, including shipping name, identification number, quantity transported, and date of shipment.

NOTE

Your source type, source activity, and TI may differ from this example. The "RQ" requirement applies only to sources containing americium-241.

Your Company's Letterhead

BILL OF LADING

Shipper: ABC Paving Company
0000 Road Drive
Anywhere, U.S.A.

Qty	Description
1 case	UN3332, Radioactive material, Type A package, Special Form, 7, RQ Cs-137, 0.30 GBq (8.0 mCi) Am-241, 1.48 GBq (40.0 mCi) Radioactive Yellow II Label, TI = 0.3

**** EMERGENCY CONTACT: (919) 549-9539 ****

Shipper Name (Print): _____

Shipper Name (Signature): _____

APPENDIX C

COMMON CARRIER BILL OF LADING FOR A 3400 SERIES GAUGE

This is an example of a bill of lading for a 3400 Series nuclear gauge being shipped by highway.

NOTE

Your source type, source activity, and TI may differ from this example. The "RQ" requirement applies only to sources containing americium-241.

SB Freightways

BILL OF LADING

DATE	P.O. NO.	SHIPPER NO.
SHIP DATE		

CONSIGNEE (TO)	SHIPPER/CONSIGNOR (FROM)
RED E. WAITING	ABC PAVING COMPANY
DEF PAVING INTERNATIONAL	456 MAIN STREET
123 DIRT ROAD	ANY OTHER TOWN, U.S.A. 67890
ANYTOWN, U.S.A. 12345	

PHONE NO.	EMERGENCY RESPONSE NUMBER* (REQUIRED IF HM COLUMN MARKED)	ROUTE
	919-549-9539	

(SUBJECT TO CORRECTION)

Number of Packages	HM *	Kind of Packaging, Description of Articles, Special Marks and Exceptions	Weight (lb)	Class or Rate Ref.	Cube (Optional)
1 case	x	UN3332, Radioactive Material, Type A package,			
		Special Form, 7, RQ			
		Cs-137, 0.30 GBq (8.0 mCi)			
		Am-241, 1.48 GBq (40 mCi)			
		Radioactive Yellow II label, TI = 0.3			
		Dim 35 x 45 x 78 cm			
		Emergency Contact: (919) 549-9539			

THIS IS TO CERTIFY THAT THE ABOVE-NAMED MATERIALS ARE PROPERLY CLASSIFIED, DESCRIBED, PACKAGED, MARKED, AND LABELED AND ARE IN PROPER CONDITION FOR TRANSPORTATION ACCORDING TO THE APPLICABLE REGULATIONS OF THE DEPARTMENT OF TRANSPORTATION.

SHIPPER/CONSIGNOR		CARRIER
WANDA SHIPPITT		SB FREIGHTWAYS
AUTHORIZED SIGNATURE	DATE	AUTHORIZED SIGNATURE

APPENDIX D

SHIPPER'S DECLARATION FOR DANGEROUS GOODS FOR A 3400 SERIES GAUGE

This is an example of a Shipper's Declaration for Dangerous Goods for shipping a 3400 Series nuclear gauge by air. For international shipments (outside the USA), enter the special form certificate numbers for the sources, along with a statement that the certificates are attached as the last line of the *Nature and Quantity of Dangerous Goods* section of the form. For example: "Special form certificates USA/0614/S and USA/0632/S attached."

NOTE

Your source type, source activity, and TI may differ from this example. The "RQ" requirement applies only to sources containing americium-241.

SHIPPER'S DECLARATION FOR DANGEROUS GOODS

Shipper
ACME PAVING COMPANY
524 ROCKY ROAD
CHICAGO, IL
USA

Air Waybill No. 548974
Page of Pages
Shipper's Reference Number 856

Consignee
APEX TESTING LABS
555 MAIN STREET
ATLANTA, GA
USA

TROXLER®

Two completed and signed copies of this Declaration must be handed to the operator

WARNING

Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of the applicable law, subject to legal penalties.

TRANSPORT DETAILS

This shipment is within the limitations prescribed for: *(delete non applicable)*
~~PASSENGER AIRCRAFT~~ | CARGO AIRCRAFT ONLY

Airport of Departure: CHICAGO, OHARE

Airport of Destination: ATLANTA, HARTSFIELD

Shipment type: *(delete non-applicable)*
~~NON-RADIOACTIVE~~ | RADIOACTIVE

NATURE AND QUANTITY OF DANGEROUS GOODS

UN Number or Identification Number, Proper Shipping name, Class or Division (subsidiary risk), Packing Group (if required), and all other required information.

UN 3332, Radioactive Material, Type A Package, Special Form, 7, RQ

Cs-137, 0.30 GBq (8 mCi)

Am-241, 1.48 GBq (40 mCi)

All packed in one Type A package

II-Yellow, TI = 0.6, Dim 35 x 42 x 75 cm

Additional Handling Information This shipment may be carried on passenger aircraft outside U.S. jurisdiction.

Emergency response sheet attached to Dangerous Goods Declaration.

Emergency Telephone Number **(011) 919-549-9539**

I hereby declare that the contents of this consignment are fully and accurately described above by the proper shipping name, and are classified, packaged, marked and labelled/placarded, and are in all respects in proper condition for transport according to applicable International and National Governmental Regulations. I declare that all of the applicable air transport requirements have been met.

Name/Title of Signatory
A. BROWN, SHIPPING MANAGER
Place and Date
CHICAGO, IL JAN. 1, 2006
Signature
(see warning above)

APPENDIX E

EMERGENCY RESPONSE INFORMATION EXAMPLE

TROXLER NUCLEAR GAUGE EMERGENCY RESPONSE INFORMATION REQUIRED FOR TRANSPORTATION

Call Troxler Electronic Laboratories, Inc. at (919) 549-9539 for Emergency Assistance.

1. PROPER SHIPPING NAME:

- Radioactive material, Type A package, Special Form, UN3332

POTENTIAL HAZARDS

2. HEALTH HAZARDS

- Radiation presents minimal risk to lives of persons during transportation accidents.
- Undamaged packages are safe; damaged packages or materials released from packages can cause external radiation hazards. Contamination is not suspected.
- Packages (cartons, boxes, drums, articles, etc.) identified as "Type A" by marking on packages or by shipping papers contain non-life endangering amounts. Radioactive sources may be released if packages are damaged in moderately severe accidents.
- Packages (large and small, usually metal) identified as "Type B" by marking on packages or by shipping papers contain potentially life-endangering amounts. Because of design, evaluation, and testing of packages, life-endangering releases are not expected in accidents except those of utmost severity.
- Commonly available instruments can detect most of these materials.
- Water from cargo fire control is not expected to cause pollution.

3. FIRE OR EXPLOSION

- Packagings can be consumed without content loss from sealed source capsule.
- Radioactive source capsules and Type B packages are designed to withstand temperatures of 1475 °F (800 °C).

EMERGENCY ACTION

4. IMMEDIATE PRECAUTIONS

- Priority response actions may be performed before taking radiation measurements.
- Priorities are life saving, control of fire and other hazards, and first aid.
- Isolate hazard area and deny entry. Notify Radiation Authority of accident conditions.
- Delay final cleanup until instruction or advice of Radiation Authority.
- Positive pressure self-contained breathing apparatus (SCBA) and structural firefighter's protective clothing will provide adequate protection against internal radiation exposure, but not external radiation exposure.

5. FIRE

- Do not move damaged packages; move undamaged packages out of fire zone.
- **Small Fires:** Dry chemical, CO_2 water spray or regular foam.
- **Large Fires:** Water spray, fog (flooding amounts)

6. SPILL OR LEAK

- **Do not touch damaged packages or spilled material.**
- Slightly damaged or damp outer surfaces seldom indicate failure of inner container.
- If source is identified as being out of package, stay away and await advice from Radiation Authority.

7. FIRST AID

- Use first aid treatment according to the nature of the injury.
- Persons exposed to special form sources are not likely to be contaminated with radioactive material.

APPENDIX F

SPECIAL FORM CERTIFICATE EXAMPLE

U.S. Department of Transportation
Research and Special Programs Administration

400 Seventh St., S.W.
Washington, D.C. 20590

IAEA CERTIFICATE OF COMPETENT AUTHORITY
SPECIAL FORM RADIOACTIVE MATERIALS
CERTIFICATE NUMBER USA/0620/S, REVISION 0

This certifies that the source described has been demonstrated to meet the regulatory requirements for special form radioactive material as prescribed in the regulations of the International Atomic Energy Agency[1] and the United States of America[2] for the transport of radioactive materials.

1. Source Identification - AEA Technology QSA, Inc. Model number X.1188.

2. Source Description - Single encapsulation made of stainless steel and tungsten inert gas or laser seal welded. Minimum wall thickness is 0.48 mm (0.02 in.). Approximate outer dimensions are 10.1 mm (0.40 in.) in diameter and 9.7 mm (0.38 in.) in length. All sources shall be constructed and maintained in accordance with attached AEA Technology QSA, Inc. Drawing number RBA61869, Rev. A.

3. Radioactive Contents - No more than 74 GBq (2.0 Ci) Americium-241 oxide mixed with Beryllium and pressed into a solid pellet.

4. Quality Assurance - Records of Quality Assurance activities required by Paragraph 310 of the IAEA regulations[1] shall be maintained and made available to the authorized officials for at least three years after the last shipment authorized by this certificate. Consignors and consignees in the United States exporting or importing shipments under this certificate shall satisfy the requirements of Subpart H of 10 CFR 71.

5. Expiration Date - This certificate expires April 1, 2008.

This certificate is issued in accordance with paragraph 804 of the IAEA Regulations and Section 173.476 of Title 49 of the Code of Federal Regulations, in response to the petition and information dated January 17, 2003 and March 18, 2003 submitted by AEA Technology QSA, Inc., Burlington, MA, and in consideration of other information on file in this Office.

Certified by:

Robert A. McGuire
Associate Administrator for
Hazardous Materials Safety

APR - 8 2003
(DATE)

Revision 0 - Original issue.

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1 "Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised), No. TS-R-1 (ST-1, Revised)," published by the International Atomic Energy Agency (IAEA), Vienna, Austria.

2 Title 49, Code of Federal Regulations, Parts 100 - 199, United States of America.

APPENDIX G

TRANSPORT INDEXES FOR TROXLER GAUGES

The Transport Index (TI) for a nuclear gauge is defined as the dose rate (mrem/h) one meter from the shipping case.

1. Determine your case type using the case drawings (see page 11).
2. Find your gauge model number in the first column of the table below.
3. Find the corresponding case in the second column of this row.
4. If the gauge was manufactured with different source activities or sources, find this information in the third column.
5. The fourth column provides the TI for each gauge, case, and source combination.
6. Gauges that are no longer in production may not be listed.
7. Please contact your Troxler representative or the Troxler corporate headquarters if you need any assistance.

GAUGE MODEL	NUCLIDES	ACTIVITY	CASE/ DRAWING #	TRANSPORT INDEX (TI)
1351, 1352, 2376	Cs-137	0.3 GBq	TRUNK/#2	0.2
3241-C	Am-241	3.7 GBq	WATER RES/#1	0.1
	Am-241	11.1 GBq	WATER RES/#1	0.5
3241-M	Cf-252	3.7 MBq	WATER RES/#1	0.1
3216, 3217, 3218	Am-241	1.48 GBq	PLASTIC/#6	0.1
			PYRAMID/#3	0.1
3242	Cf-252	3.7 MBq	WATER RES/#1	0.4
3401	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1 or BLOWMOLD/#4	0.4
			TRUNK/#2, PYRAMID/#3, or ABS/#5	0.1
3411	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1	0.5
			TRUNK/#2, PYRAMID/#3, or ABS/#5	0.1
			BLOWMOLD/#4	0.4
3430	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1	0.3
3430M, 3440M	Cs-137 Cf-252	0.3 GBq 2.22 MBq	WATER RES/#1	0.6
3440	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1	0.6
			TRUNK/#2	0.5
3440-L	Am-241 Cs-137	0.56 GBq 0.3 GBq	WATER RES/#1	0.4
3430 Plus, 3440 Plus	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1	0.3
3450, 3451	Am-241 Cs-137	1.48 GBq 0.3 GBq	WATER RES/#1	0.3
4232	Cf-252	3.7 MBq	WATER RES/#1	0.4
4350	Am-241 Cs-137	0.15 GBq 0.3 GBq	WATER RES/#8	0.2
4430	Am-241 Cf-252	0.15 GBq 2.22 MBq	TRUNK/#7	0.1
4440 SERIES	Co-60 Cf-252	2.22 MBq 1.11 MBq	WATER RES/#1	0.1
4545	Cs-137	0.3 GBq	TRUNK/#2	0.2
4640 SERIES	Cs-137	0.3 GBq	WATER RES/#1 or TRUNK/#2	0.2

Appendix H

Operating and Emergency Procedures

Operating Procedures

- If personnel dosimetry is provided:
  - — Always wear your assigned thermoluminescent dosimeter (TLD) or film badge when using the gauge;
  - — Never wear another person's TLD or film badge;
  - — Never store your TLD or film badge near the gauge.
- Before removing the gauge from its place of storage, ensure that, where applicable, each gauge source is in the fully shielded position and that in gauges with a movable rod containing a sealed source, the source rod is locked (e.g., keyed lock, padlock, mechanical control) in the shielded position. Place the gauge in the transport case and lock the case.
- Sign out the gauge in a log book (that remains at the storage location) including the date(s) of use, name(s) of the authorized users who will be responsible for the gauge, and the temporary job site(s) where the gauge will be used.
- Block and brace the gauge to prevent movement during transport and lock the gauge in or to the vehicle. Follow all applicable Department of Transportation (DOT) requirements when transporting the gauge.
- Use the gauge according to the manufacturer's instructions and recommendations.
- Do not touch the unshielded source rod with your fingers, hands, or any part of your body.
- Do not place hands, fingers, feet, or other body parts in the radiation field from an unshielded source.
- Unless absolutely necessary, do not look under the gauge when the source rod is being lowered into the ground. If you must look under the gauge to align the source rod with the hole, follow the manufacturer's procedures to minimize radiation exposure.
- After completing each measurement in which the source is unshielded, immediately return the source to the shielded position.
- Always maintain constant surveillance and immediate control of the gauge when it is not in storage. At job sites, do not walk away from the gauge when it is left on the ground. Take action necessary to protect the gauge and yourself from danger of moving heavy equipment.
- Always keep unauthorized persons away from the gauge.
- Perform routine cleaning and maintenance according to the manufacturer's instructions and recommendations.
- When the gauge is not in use at a temporary job site, place the gauge in a secured storage location (e.g., locked in the trunk of a car or locked in a storage shed).

- Before transporting the gauge, ensure that, where applicable, each gauge source is in the fully shielded position. Ensure that in gauges with a movable source rod, the source rod is locked in the shielded position (e.g., keyed lock, padlock, mechanical control). Place the gauge in the transport case and lock the case. Block and brace the case to prevent movement during transportation. Lock the case in or to the vehicle, preferably in a closed compartment.
- Return the gauge to its proper locked storage location at the end of the work shift.
- Log the gauge into the daily use log when it is returned to storage.
- If gauges are used for measurements with the unshielded source extended more than 3 feet beneath the surface, use piping, tubing, or other casing material to line the hole from the lowest depth to 12 inches above the surface. If the piping, tubing, or other casing material cannot extend 12 inches above the surface, cap the hole liner or take other steps to ensure that the hole is free of debris (and it is unlikely that debris will re-enter the cased hole) so that the unshielded source can move freely (e.g., use a dummy probe to verify that the hole is free of obstructions).
- After making changes affecting the gauge storage area (e.g., changing the location of gauges within the storage area, removing shielding, adding gauges, changing the occupancy of adjacent areas, moving the storage area to a new location), reevaluate compliance with public dose limits and ensure proper security of gauges.

Emergency Procedures

If the source fails to return to the shielded position (e.g., as a result of being damaged, source becomes stuck below the surface), or if any other emergency or unusual situation arises (e.g., the gauge is struck by a moving vehicle, is dropped, is in a vehicle involved in an accident):

- Immediately secure the area and keep people at least 15 feet away from the gauge until the situation is assessed and radiation levels are known. However, perform first aid for any injured individuals and remove them from the area only when medically safe to do so.
- If any heavy equipment is involved, detain the equipment and operator until it is determined there is no contamination present.
- Gauge users and other potentially contaminated individuals should not leave the scene until emergency assistance arrives.
- Notify the following persons, in the order listed below, of the situation:

NAME[2]	WORK PHONE NUMBER[2]	HOME PHONE NUMBER[2]
_____	_____	_____
_____	_____	_____
_____	_____	_____

Follow the directions provided by the person contacted above.

RSO and Licensee Management

- Arrange for a radiation survey to be conducted as soon as possible by a knowledgeable person using appropriate radiation detection instrumentation. This person could be a licensee employee using a survey meter located at the job site or a consultant. To accurately assess the radiation danger, it is essential that the person performing the survey be competent in the use of the survey meter.
- If gauges are used for measurements with the unshielded source extended more than 3 feet below the surface, contact persons listed on the emergency procedures need to know the steps to be followed to retrieve a stuck source and to convey those steps to the staff on site.
- Make necessary notifications to local authorities as well as to NRC as required. (Even if it is not required, you may report *any* incident to NRC by calling NRC's Emergency Operations Center at (301) 816-5100, which is staffed 24 hours a day and accepts collect calls.) NRC notification is required when gauges containing licensed material are lost or stolen, when gauges are damaged or involved in incidents that result in doses in excess of 10 CFR 20.2203 limits, and when it becomes apparent that attempts to recover a source stuck below the surface will be unsuccessful.
- Reports to NRC must be made within the reporting time frames specified by the regulations.
- Reporting requirements are found in 10 CFR 20.2201-2203 and 10 CFR 30.50.

[2] Fill in with (and update, as needed) the names and telephone numbers of appropriate personnel (e.g., the RSO or other knowledgeable licensee staff, licensee's consultant, gauge manufacturer) to be contacted in case of emergency.