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NUCLEAR WASTE MANAGEMENT PROGRAM PROCEDURE

SP 9-2
NEUTRON PROBE TESTING IN THE DRZ
Revision 0

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1.0 Purpose and Scope

This procedure prescribes the Sandia National Laboratories (SNL) Nuclear Waste Management Program (NWMP) procedure for measuring moisture content in the WIPP underground salt with Troxler™ model 3223 Neutron Probes. Calibration and operation guidelines are included in the procedure (see Appendix A). This SP is in support of activities described in TP 99-04, Section 5.5 for moisture content analysis of the Disturbed Rock Zone (DRZ). Both SNL and Westinghouse Waste Isolation Division (WID) personnel will use this SP.

Acronyms and definitions for terms used in this procedure may be found in the NWMP Glossary located at the Sandia National Laboratories (SNL) NWMP On-line Documents web site.

2.0 Implementation Actions

The Troxler™ 3223 moisture gauge is an off-the-shelf item that includes a comprehensive manual for operating instructions. This SP will refer to the manual where appropriate and include additional procedures for operating a custom data acquisition system, SNL radioactive source control, and specific procedures for use in WIPP salt and the WIPP underground. SNL staff (org. 6821) will provide design, implementation and technical assistance for the DRZ monitoring program. This SP is specifically for the operation of the

Troxler™ gauge in measuring moisture content of the DRZ. WID personnel will be responsible for monitoring program once it is in place. Data identification and use from the measurements are described in TP99-04 Section 6.1.4.

2.1 Neutron Probe Operation

Standard operating instructions for the Neutron Probe is described in Section II of the manual for Troxler 3200 series moisture gauges (see Appendix A). A custom data acquisition system has been added for more versatility in counting. The following describes the operation of this system. The data acquisition is accomplished by interfacing an Eberline Smart Portable (ESP-2) radiation instrument to the direct output of the Neutron Probe. The ESP-2 is a data logging, microcomputer-based, portable radiation instrument, designed to operate with radiation detectors. It is designed for radiation counting and allows multiple readings (up to 500), to be stored and later output to a computer or printer. The ESP-2 may also be used in remote areas operated solely by a computer via its RS232 serial communications port.

The ESP-2 features a liquid crystal display (LCD) along with a single row of seven multi-function pushbutton switches as it interface to the user. Data are presented in either scientific or floating point notation and have selectable measurement units. Complete detector configuration including High Voltage (HV) setting, calibration, and operating mode can be specified for up to three different detectors and stored by the ESP-2. In our case, the Troxler unit contains its own HV supply, so the HV on the ESP-2 was disabled. In operation, the detector signal is input to the computer and converted to count rate. The basic unit is counts per second. The Scaler Mode,(Integrating or Average Rate) allows the user to select a counting period over which the computer integrates the detector's signal. In the Scaler mode the first line of the LCD displays the time remaining in the counting period. The second line shows the cumulative "events". At the end of the counting period the instrument displays the length of the counting period and the total number of events or radiation units detected. The ESP-2 stores logging information such as the date, time, instrument number, user ID, detector selected, operating mode, calibration, and each data point collected.

The ESP-2 is powered by six "C" cell alkaline batteries. These batteries provide approximately 300 hours of continuous use. The ESP-2 senses low battery conditions at 0.95Vdc/cell and signals the user by blinking the first character on the display. This indicates that at least 2 hours of operation remain before the end of battery life. To allow battery change without loss of memory the ESP-2 uses a charged capacitor to supply power to the computer. If extended continuous use of the ESP-2 is anticipated, an optional ac power unit will be incorporated into the unit.

2.2 Source Control

The Am-241/Be sealed radioactive source in the probe must be registered with the SNL Source and Device Control Program prior to acceptance by SNL. A primary and secondary custodian of the source must be chosen. Changes in source custodian(s) must also be registered with the SNL Source and Device Control Program.

2.3 Calibration in WIPP Salt

Calibration procedures are described in Section IX of the manual for Troxler™ 3200 series moisture gauges (see Appendix A). For WIPP salt, four standards were made to generate a calibration curve for moisture in salt. These standards were developed to give equivalent Hydrogen contents for water volume fractions of 0%, 2.5%, 5%, and 15%. Detailed information regarding the standards is in the DRZ Moisture Studies laboratory notebook (Org. 6821, task # 1.2.01.09.03.02). Using these WIPP salt standards, follow the instructions described in Section IX of the manual for Troxler™ 3200 series moisture gauges (see Appendix A). Calibration must be done quarterly and recorded in a laboratory notebook.

2.4 Moisture Measurements in the DRZ

The moisture measurements in the DRZ will be performed by placing the probe of the moisture gauge into the aluminum lined 1.75 in diameter bore-holes in the panel walls. The bore-holes will be drilled according to SP 9-? and rubber stoppers are to be placed in the tubing when not in use to keep moisture from transferring in or out of the bore-hole. The probe will be placed at various depths of interest into the panel wall. Distance into the wall can be measured and controlled using cable stops on the probe's cable. These cable stops are metal rings that attach to the cable and access port for the cable in the probe housing. Proceed as follows:

1) First install all tubes so they protrude the same distance out of the panel wall. This will enable stops to be fastened and used for all tubes.
2) Then mark the shallowest depth measurement by placing the cable stop the distance the tube is out of the wall plus the desired depth above the centerline of the probe.
3) Then place stops at desired intervals above the first stop.

The measurement at each depth must taken in time intervals such that at least 10,000 counts are obtained. The counts and count time must be recorded by saving data on disk before measurement of the next desired depth. It may take several hours to obtain the required counts and the system may be left unattended during this time.

2.5 Safety and Training

The safety concerns regarding the Neutron Probe are solely due to the Am-241/Be radiation source. Section X of the manual for Troxler 3200 series moisture gauges (see Appendix A) thoroughly describes the radiation characteristics and handling procedures for the moisture gauge. In addition, users of the moisture gauge must have Radiological Worker II training.

3.0 Records

Calibration data shall be recorded in laboratory notebooks and DRZ moisture data shall be recorded on disk and stored separately from the data acquisition system for the moisture gauge. These records shall be prepared and submitted to the NWMP Records Center in accordance with NP 17-1 (Records). The following table summarizes the QA records requirements.

QA Record	Preparer	Records Submitter
• Gauge Calibration	Technician/PI	Technician/PI
• Lab Notebook	Technician/PI	Technician/PI
• Data Disk	Technician/PI	Technician/PI

4.0 Appendices

Appendix A: Excerpts from the Troxler™ Series 3200 Manual.

II. OPERATING INSTRUCTIONS

II-A. GETTING ACQUAINTED

The 3220 Series of instruments provide a fast and economical method for determining the moisture content of materials. Before you attempt to use your gauge, spend a few minutes learning its features and controls. This section will act as a “Dry Run” to acquaint you with the instrument. Remove the gauge and accessories from the shipping case and identify all the items by referring to Figure 2-1. A brief description of the parts is:

Gauge: Portable instrument containing all electronic modules, re-chargeable battery packs, and radioactive source. The reference standard, batteries, high voltage power supply, and other electronics are located in the gauge body. The detector, radioactive source, and preamplifier are located in the probe which comes out of the bottom of the unit.

Reference Standard: This piece of polyethelene contained within the gauge serves two purposes. First, it is used to establish the standard counts against which all measurements are proportional; second, it serves as a known repeatable reference for checking long term stability.

Charger: Two chargers are supplied. Refer to Section V-A for use of these units.

3220 Gauge and Accessories
Figure 2—1

II-A-1. DETERMINATION OF THE STANDARD COUNT

The calibration of this instrument is made in terms of a ratio to a standard count made with the probe secured within the gauge body. For this reason, measurements made with the instrument can be no more accurate than the accuracy of the standard count. The operator should therefore use care to establish the standard count. A log should be kept of the counts throughout the life of the instrument since this will establish a norm for the rate of change per unit time and allow the user to determine when a defect occurs either in the procedure or the instrument.

In general, a sudden shift of more than 2% in an individual standard count, as compared to the average of the previous four, indicates some abnormality in gauge operation or procedure.

While accumulating a standard count, the gauge should be at room temperature or at least between 10 and 30°C (50–86°F). The material used to construct the reference standard contracts and expands with changes in temperature. These changes can affect the standard count and therefore the measurement results. Place the gauge on the access tubing. This should be at least two meters (six feet) away from any building or other large structure and at least ten meters (thirty feet) from any other source of neutrons.

The probe must be secured within the gauge body and locked in place by the gauge lock on top of the instrument.

The gauge can now be used to accumulate (count) the standard count.

II–A-2. 3220 SERIES CONTROL FUNCTIONS AND OPERATIONS

The data processor module used in the 3220 Series of gauges contains a μP (microprocessor) as its key component. The μP has been programmed to provide a variety of functions. While the computational power of this module is quite large, considerable effort was spent making the unit as easy to use as possible.

a. Below is a functional description of the 3220 Series controls. The number before the description corresponds to the labels in Figure 2-2.

1 The instrument display is a type of liquid crystal. In addition to displaying accumulated counts and computed results, it also has status indicators as shown below:

ERR - Accumulation in progress or a computational error has occured.

BAT - Low battery warning. Instrument battery is in need of recharge. The gauge will still function normally for several hours before it automatically shuts off.

– - Displayed number is negative in value.

2 POWER/TIME switch turns the unit on and also selects the time period for an accumulation. The SLOW, NORM, or FAST positions correspond to accumulate periods of 4 minutes, 1 minute, or 0.25 minute, respectively.

3220 Series Front Panel Controls
Figure 2–2

II-A-2. 3220 SERIES CONTROL FUNCTIONS AND OPERATIONS (cont'd)

3 START - This pushbutton switch initiates either a standard count or a measurement count depending on the position of the DISPLAY switch. If the DISPLAY switch is in one of the computaional positions, the unit will also make a computation of the measured moisture immediately following the measurement count. This switch is also used to enter a program to alter the gauge calibration.

4 DISPLAY - The display switch has many positions which instruct the μP to perform certain instructions.

STD COUNT - This position tells the μP to display the number stored in the standard count register. The μP assumes that any count taken in this position is the standard count. Therefore, the probe must be secured inside the gauge body and the POWER/TIME switch placed on SLOW.

MEAS COUNT - This position tells the μP to display the number stored in the measure count register. The probe should be in the material to be tested and the POWER/TIME switch usually set to NORM.

PCF, kg/m^3, and %VOL - These positions instruct the μP to compute the moisture content in the selected units, using the currently stored values for STD COUNT, MEAS COUNT, ZERO, and SLOPE. If the DISPLAY switch is placed in one of these positions prior to accumulating a standard count, an error message will be displayed. If a standard count has been taken but no measure count, a value will be computed and displayed. An explanation of this result is covered in section II—B—4.

ZERO, SLOPE - These two positions allow the user to alter the gauge's factory calibration to correct for errors which may exist in his particular application. The use of these functions is covered in section II—A—2—j.

TEST - This position initiates a cyclic test of the display (See Section II-B—3). If the gauge passes this test, you can assume (with a high degree of confidence) that the μP is functioning normally.

5 OFFSET - The two pushbuttons labeled INC and DEC are used in conjunction with the ZERO and SLOPE functions to alter the calibration.

II—A-2. 3220 SERIES CONTROL FUNCTIONS AND OPERATIONS (cont'd)

Now that you are familiar with the controls of the 3220 Series, proceed as below to use the gauge.

b. Place the gauge on the access tubing adhering to the precautions outlined in section II—A—1.

c. Turn the POWER/TIME switch to SLOW. The standard count will always be taken in the SLOW position. Place the DISPLAY switch on STD COUNT.

d. Allow at least ten minutes to elapse after powering the instrument before taking the standard count.

e. Depress START and note that ERR appears in the upper left corner of the display. During the four-minute period the value in the display will be increasing at a random rate. This value will remain in the µP until another standard count is taken or the instrument is turned off. It can be displayed and read at any time by placing the DISPLAY switch on STD COUNT.

f. Unlock the the probe lock located on top of the gauge body to allow the probe to drop into the access tubing. Lower the probe into the tubing to the desired depth, noting the depth by the markings on the cable. Secure the probe at the desired depth using the cable clamp provided.

g. Set the POWER/TIME switch on NORM and the DISPLAY switch on MEAS COUNT, then depress START. ERR will appear in the display indicating that an accumulation is taking place. At the end of the NORM period, ERR will disappear and the register will indicate the moisture measurement count.

h. If the DISPLAY switch is now placed in any of the MOISTURE CONTENT positions, the value will be displayed in the selected units of measurement.

i. Assuming that a unit of measurement has been selected, START may be depressed, the gauge will accumulate, compute and display the measured value without having to go through the various positions of the display switch.

II-A-2. 3220 SERIES CONTROL FUNCTIONS AND OPERATIONS (cont'd)

j. If an error exists due to the nature of the material and the correct value of moisture is known, two methods of correcting the calibration are available. The proper one to use is covered in section _____of the manual. Proceed with the following procedures with the last moisture content displayed from above.

ZERO - Move the DISPLAY switch to ZERO, the display will indicate 0000. Press START, the processor is now in a program to change the gauge calibration by simply offsetting the entire equation. Successful entry into the program is evidenced by the appearance of colons in the display. Pressing INC or DEC will increase or decrease the displayed value. Move the DISPLAY switch to one of the MOISTURE CONTENT positions and the INC or DEC switches will alter the computed value until the correct value is reached. Return the DISPLAY switch to ZERO and press START to exit the ZERO shift mode. Successful exit from the program is evidenced by the disappearance of the colons in the display. The final value of the offset should be recorded for future use.

SLOPE - Move the DISPLAY switch to SLOPE, the display will indicate 1.000. Press START, the processor is now in a program to change the gauge calibration by changing the slope of the equation. The procedure is the same as described above under ZERO. The final value for slope should also be recorded for future use.

ZERO and SLOPE can be restored to their initial values by using the procedures described above or by simply turning off the instrument. The ZERO and SLOPE values obtained in the foregoing procedures should be recorded for future correction on the same type material.

II-B. 3220 SERIES TEST FUNCTIONS

The 3220 Series contains a µP (Microprocessor) which controls the majority of the instrument's functions. The µP, in conjunction with its crystal oscillator, provides the time standard for the accumulation cycle. The µP also updates the display, accumulates the data counts, responds to the rotary switches, and generates an error code if improper operation is detected. Therefore, the µP must be operational before any test can be performed. Fortunately, if the µP fails, it normally fails catastrophically. If the display indicates four zeros when the instrument is turned on, the µP is probably working normally.

II-B-1. ALARM BUZZER

An alarm is enclosed in the unit. It will beep upon completion of certain operations and also upon certain error conditions. Below is a list of the conditions under which an alarm occurs.

Power-up ----------- Single beep to indicate correct start-up sequence.

End of Accumulate -- Single beep to indicate the end of an accumulation period.

Operational Errors - Repetitive beeps for a six second interval. The alarm will be accompanied by a display error code that indicates a "non—standard use procedure". The operator has six seconds to change the mode of operation before prior data is destroyed by the pending operation. See Error Codes 21 and 22 in section II—B-2.

II-B-2. ERROR CODES

If the μP detects an error condition it will halt normal operation and begin indicating an error code via the display. The ERR symbol and a two digit number are flashed on and off. Below is a list of the error codes.

ERROR CODE	INDICATED FAILURE MODE	PROBABLE CAUSE	COMMENTS
02	Number to be displayed exceeds display range	Position of POWER/TIME switch was changed during an accumulation	
10	μP attempted to divide by zero	Standard count is zero	Accumulate a standard count
11	Positive overflow	Standard or measure counts are not valid	Compare counts with past data
12	Negative overflow [μP attempted a math operation on a number that exceeded the capacity of the device]	OR Slope of calibration curve was altered drastically	
24	Improper exit from increment/decrement routine	Attempted to enter test routine while still in increment/decrement mode	
25	Improper operation	Attempted to accumulate a measure count before a standard count	
31	Open DISPLAY switch	Defective switch or hard-ware failure (switch not properly seated in detents)	

Note: The following error codes result from non-standard use procedures. Since these types of errors are normally unintentional, the μP will indicate the error code for approximately six seconds before it performs the selected operation. If the selected operation was unintentional, you may select the desired function within the six second interval without destroying the data.

21	Non-valid condition for standard count	Attempted to accumulate a standard count in the FAST or NORM position	Standard counts should always be taken in the SLOW position
22	Repetitive standard counts	Attempted to accumulate two successive standard counts	Operator error normally caused by forgetting to change the DISPLAY switch after a standard count

II-B-3 SELF-TEST ROUTINE

If the μP is working, an internal self-test routine can be used to verify proper operation. While this routine appears to be only checking the display, the entire μP must be operational to perform this test. If the μP successfully executes this routine, you may safely assume that the digital portion of the electronics is working normally.

The routine produces a cyclic number sequence that ripples across the display. The exact sequence is shown at the lower right. By watching each digit "count up" you can verify that the LCD (Liquid Crystal Display), its associated electronics, and the μP are operating correctly.

Display Test Sequence
Figure 2-3

II-B–4. TEST COMPUTATION

At the bottom of the Calibration Data Sheet for the 3220 Series Gauge (see figure 9-2 for an example) is a heading labeled TEST VALUES. With a ratio of one (ie. MS = MC) and the stated conditions of slope and offset, the gauge should display these values. (This condition is met immediately after taking a standard count.) If the values calculated by the gauge do not agree with those on the sheet, either the gauge is defective or the Calibration Data Sheet is for another gauge.

IX. FACTORY CALIBRATION

IX-A. CALIBRATION STANDARDS AND PROCEDURE

Many attempts have been made to create satisfactory stable moisture standards either by using actual water and soil mixes or simulating moisture by mixes of hydrogen bearing materials with other materials simulating soils. Some are totally inaccurate and others are very unstable unless particular attention is made to maintaining water levels and preventing evaporation.

During the development of this gauge and others, Troxler Electronic Laboratories, Inc. developed a set of standards made from laminated sheets of plastic and a non-absorber of thermal neutrons. The process has been patented. During the process of manufacture the ratio of plastic (or other hydrogen bearing material) and non-absorber can be accurately controlled. Laminations were chosen to insure uniformity rather than mixing of small particles which tend to segregate due to the differences in specific gravity. The materials are non-hydroscopic and have zero voids so changes in humidity do not affect the equivalent water content.

The standards range from zero moisture-equivalent to well over 100% moisture—equivalent. Several methods were used to determine the equivalent moisture content in relation to soils which contain no “bound hydrogen” nor thermal neutron absorbing elements (ie. silica sand).

First, the thermalizing and absorption cross sections of water were computed and compared to the same quantities of the plastic which were used. While this comparision gave reasonable results, it was felt that errors would result due to resonances which occur at energies above thermal, but less than the original neutron energy. This could occur due to replacement of the oxygen content of water with the carbon content of the plastic.

A nuclear moisture gauge can be designed with a response which, although not linear, can be described by using a polynomial over a range well past the equivalent hydrogen content of pure water. A method was chosen which consists of calibrating the gauge against percent plastic and then making a measurement in pure water to determine the equivalent water content of the various standards. The resulting calibration was checked against saturated and drained sand standards thus verifing the results to within a few percent.

The count ratio data is reduced by least-squares—fit to a third order polynomial:

$$M = A_0 + O_f + S(A_1X + A_2X^2 + A_3X^3)$$

Where M = Moisture Content

X = Count Ratio or $= \dfrac{\text{Measurement Count}}{\text{Standard Count}}$

A_0, A_1, A_2, and A_3 = Coefficients

O_f = Offset (normally, zero)

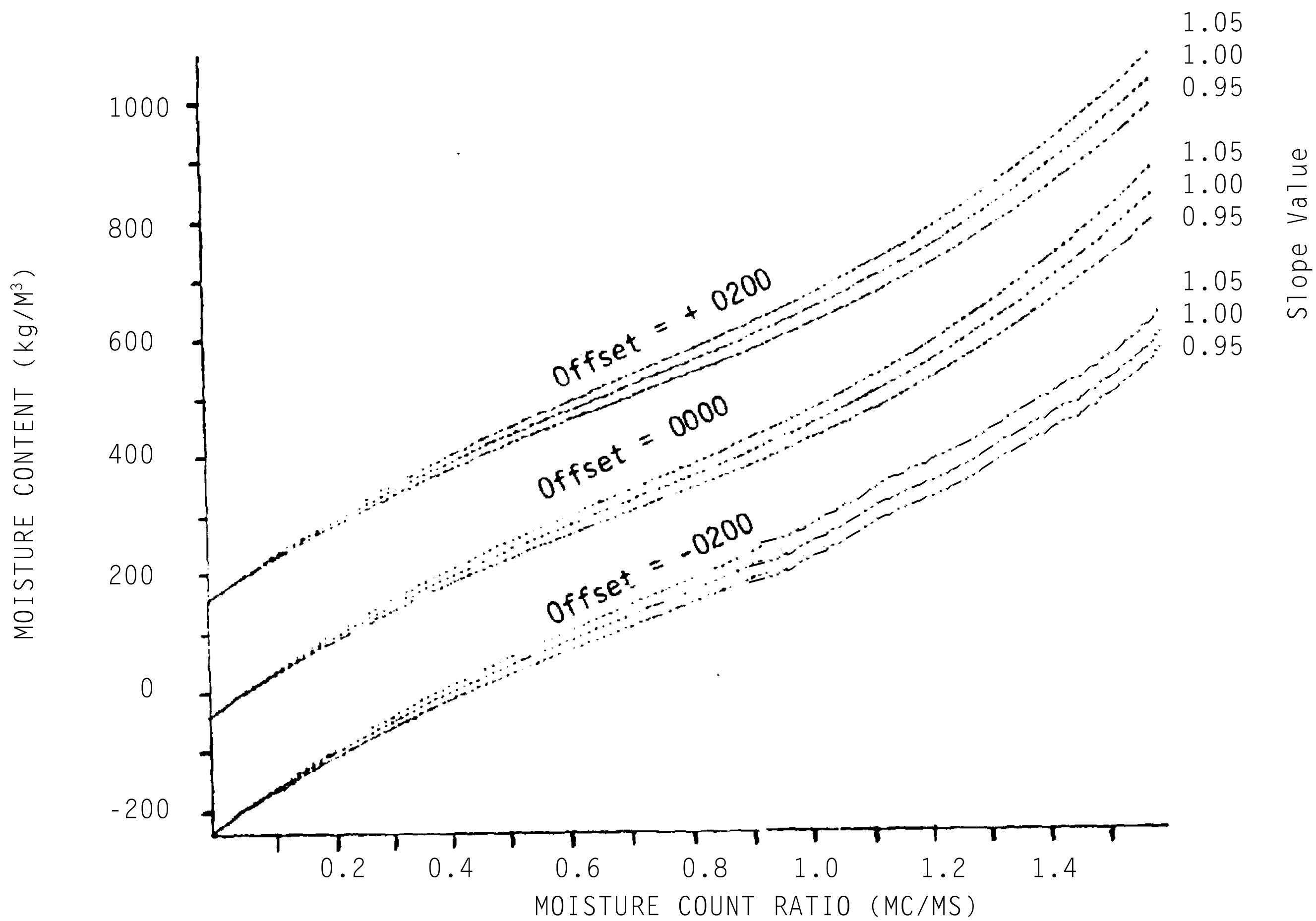
S = Slope (normally, one)

IX—A. MOISTURE CALIBRATION (cont'd)

The calibration which is supplied with the instrument is printed in tabular form with the offset set at zero and the slope set at one.

The equation which is programmed into the gauge is identical to that shown before. The value of offset is zero and the slope is 1.000 for the printed calibration. Provision is built into the instrument to allow the user to alter the values of offset or slope in order to change the calibration of the instrument for use on materials which may contain hydrogen other than free water and elements which can absorb thermal neutrons (see section IV-F).

The way in which changes in offset and slope affect gauge response is shown in Figure 9—1.



Moisture Gauge Response
Figure 9-1

IX—B. MOISTURE PERFORMANCE PARAMETERS

A printed cover sheet is supplied with the gauges. The sheet defines several parameters which need to be explained. The values are listed in SI units and may be converted by the user to any desired units. An example of this sheet is shown in figure 9-2.

1. The section headed Calibration Count Rate Data is simply the values of the moisture equivalency of the standards which were used and the counts and count ratios obtained in the various calibration standards.

2. The second section contains the data from the third order regression analysis including the errors, correlation coefficient, and the standard error of estimate. The coefficients listed apply to the equation in section IX-A.

3. Since the precision varies over the range of use, the third section lists the value of precision for a range of moisture contents.

4. The last section lists the moisture values which will be obtained if a moisture content is processed by the gauge for a count ratio of 1.000. The use of this value is explained in section II-B—4. The values in figure 9—2 is an example only; the actual values for a particular gauge are printed on that gauge's data sheet.

X. RADIOLOGICAL SAFETY

The quantities of radioactive material contained in Troxler moisture gauges are quite small, and an operator may safely use a gauge daily without receiving any bodily damage due to radiation. In addition, each radioactive source is doubly encapsulated to afford even greater protection for the operator. However, all radioactive sources, no matter how small, should be handled with care.

The purpose of this section is to acquaint the operator with the types and characteristics of radiations with which he will be working, and to describe the routine handling procedures and precautions which should be followed in order to obtain safe and efficient operation of Troxler gauges.

X-A. RADIATION CHARACTERISTICS

X-A-1. TYPES OF RADIATION

The radioactive source in this gauge emits three types of radiation which the operator should know about: alpha particles, photons, and neutrons. Of these three, the alpha particles are completely stopped by the walls of the source container.

Photons (sometimes called gamma rays) are a form of electromagnetic radiation, somewhat similar to radio waves and light rays, and are electrically neutral. However, unlike light rays, photons are very penetrating and may pass through several inches of lead or concrete without being altered. The energy of a photon is usually expressed in units of millions of electron volts, or MeV. This need not be discussed any further except to state that, in general, the higher the energy, the more penetrating the photon will be.

When a photon (gamma ray) enters a slab of material, any of three things may happen. First, the photon may be absorbed (stopped) by the material. Second, the photon may be deflected or “scattered” in the material, and come out of the material with a different direction and lower energy than when it entered (of course, sometimes the photon is scattered several times before being absorbed or coming out of the material). Third, the photon may pass through the material without being scattered or absorbed.

It is impossible to accurately predict what will happen to a single photon entering a given material. However, if a beam of photons is directed at the material, it is possible to calculate the percentages of the beam that will be absorbed, scattered, or transmitted. The percentage of photons that will pass through a material depends mostly on the energy of the photons and the density of the material. For example, if a beam of 1.25 MeV photons is directed at concrete which is 285 mm (11.2 inches) thick, 10% of the beam would be transmitted. However, only 44 mm (1.73 inches) of lead would be required to reduce the same beam to 10%, because lead is much denser than concrete.

X-A-1. TYPES OF RADIATION (cont'd)

Neutrons are very small, dense particles. They are electrically neutral and quite penetrating. Unlike gamma rays, the penetrating power of neutrons through a material does not depend on the density of the material, but on the material composition. Neutrons are slowed down most effectively by a material containing a high percentage of hydrogen (such as water or polyethylene). For this reason, neutrons are used to measure the moisture content of soils and other materials.

X-A-2. RADIATION UNITS

Although there are many units of radiation measurements, the operator of the gauge need only be familiar with two of them. These are the curie (Ci) and the Roentgen Equivalent Man (rem). The curie is defined as the quantity of any radioactive material giving 3.7×10^{10} disintegrations per second and is approximately equivalent to the number of disintegrations in one gram of radium–226. The source used in this gauge is small and is expressed in millicuries (mCi).

The effect of the various types of radiation on the human body is defined as the quantity of radiation of <u>any</u> type that produces the same effect in man as that resulting from the absorption of one roentgen of x or gamma radiation. The unit is the "roentgen equivalent man" (rem). Since the absorbed dose is generally small when working with this equipment, the millirem (mrem) is generally used.

The neutron dose rate (mrem/hour) at any point from the unshielded americium–241:beryllium source can be calculated for any distance (D) in millimeters and is equal to $25{,}000/D^2$. For several values of "D", the dose rate in mrem/hour is given in the table below.

Distance (mm)	Neutron Dose Rate (mrem/hr)
10	250.0
50	10.0
100	2.25
500	0.10
1000	0.023

Dose Rate for an Unshielded 3220 Series Source
Figure 10–1

X-A-3. TYPES OF SOURCES

The 3220 Series of instruments is only available with americium-241: beryllium neutron sources.

The source meets or exceeeds NRC, DOT, and IATA regulations for “SPECIAL FORM” or sealed sources. Except for the direct radiation hazards, the sources are extremely safe.

The source is a compacted mixture of americium oxide and the beryllium metal target. The mixture nominally contains 10 mCi of americium-241. The mixture is fusion welded in two separate stainless steel capsules and is contained within the probe.

The americium-241 material decays with the emission a 5.45 MeV alpha particle and a gamma photon of 0.06 MeV. The half—life of this decay is 458 years. Other minor daughter product emissions are present, but not significant. The gamma yield of 1.4 x 10^8 photons per second is mainly absorbed by the capsule along with all of the 3.7 x 10^8 alphas per second. Some of the alphas are absorbed by the beryllium target material, producing a $Be^9(\alpha,n)C^{12}$ reaction. Other alpha part-icles are self-absorbed by the americium-241. The carbon-12 has excess energy and produces a small quantity of 1-9 MeV photons. The final result is effectively a neutron source of 2.5 x 10^4 neutrons per second with an average energy of 4.5 MeV and less than 1.4 x 10^8 gammas per second at an energy of 0.06 MeV.

X-A-4. EXPOSURE LIMITATIONS

In order to protect personnel from overexposure to radiation, the U. S. Huclear Regulatory Coriii~1ssion and the Federal Radiation Council have established exposure limits for radiation workers. These limits have also been adopted by the various agreement states. The limits, ex-pressed in mrems, are reproduced in the following table.

Type of Exposure	Millirem Limits for 13 weeks	1-week rate
Sensitive Regions (whole body, eyes, gonads, skull)	1,250	96
Kidneys, spleen, lungs, liver	5,000	385
Skin of whole body	7,500	577
Hands, arms, feet, ankles	18,750	1,442

Exposure Limits for Radiation Workers
Figure 10—2

X-A-4. EXPOSURE LIMITATIONS (cont'd)

A licensee may permit an individual to receive a dose to the whole body greater than that above, provided: (1) the dose during the 13 week quarter does not exceed 3 reins and (2) the dose to the whole body does not exceed [5 x (N-18)]rems; where N equals the individual's age.

These limits are intended to be highly conservative, and do not represent the absolute maximum exposure a person could receive without becoming ill or suffering radiation damage. However, it is advisable to remain as much below the limits as possible. This can be done quite easily with Troxler gauges, by following established handling procedures.

X-A-5. PROTECTION AGAINST RADIATION

There are three basic ways in which a person can protect himself from radiation: Time, Distance, and Shielding. Usually no single method is relied upon to be a complete radiation protection program. Rather, all three are utilized, the relative contribution of each method is determined by the circumstances of the radiation exposure.

X-A-5-a. TIME

Time can be very effective in reducing radiation exposure. Very simply, by limiting one's time close to a source of radiation, the radiation dose is lowered proportionately. In other words if it isn't necessary to be close to the gauge, don't be.

X-A-5-b. DISTANCE

As a person moves away from a source, the amount of radiation which he is receiving from the source falls off sharply. In fact, the radiation obeys the "inverse square" law which states that the radiation intensity decreases as the inverse square of the distance from the center of the source to the "target". Stated mathematically, the inverse square law is:

$$I_1 D_1^2 = I_2 D_2^2$$

Where I = Intensity and
D = Distance

For example, if a person standing one foot from a source were receiving forty millirems per hour, moving back another foot would cut the intensity to ten millirems per hour. By moving back, the person presents a smaller "target area" to the source. The inverse square law is illustrated by the data in figure 10—1.

X-A-5. PROTECTION AGAINST RADIATION (cont'd)

X-A-5-c. SHIELDING

The third method of radiation protection is the placing material between the source and the target. To a reasonable approximation, it makes no difference where the shielding material is placed between the source and the target, as long as the thickness of the shield remains the same.

As was mentioned earlier, dense material provides the best shielding against gamma radiation; while hydrogeneous (hydrogen containing) material affords good protection against neutrons. The 3220 series gauges use lead as the biological shield for gamma radiation and polyethylene as shielding for neutrons.

The neutron dose rate is also kept to reasonable levels by limiting the neutron yield of the source. Dose rates for a 3220 Series gauge are shown below. The dose rates given are the highest levels around or over the instrument.

Distance (Meters)	Top or Bottom	Sides	Handle
Surface	1.10	2.00	0.13
0.1	0.40	0.39	-
0.3	0.12	0.09	-
1.0	0.02	0.01	-

3220 Series Dose Rates in mrem/hr
Figure 10—3

X-A-6. OPERATOR EXPOSURE

Using the dose rate data for the 3220 and exposure limits as prescribed by the U. S. N. R. C., it can easily be shown that no hazardous exposure can be received by the operator if reasonable procedures are used. As an example, the operator could place his body on the surface of the instrument for 48 hours each week before reaching the maximum level for the body. Assuming a distance of 0.4 meters (16 Inches) from the instrument during operation, he could use the instrument for 1283 hours each week without exceeding the maximum levels for the sensitive parts of his body. Obviously, these conditions would never normally exist.

Under average conditions, a full time operator working a 40 hour week can expect to receive about 3 mrem per week or 39 mrem per 13 weeks to his whole body and approximately 25% higher to his hands. This dose is only 3% of the maximum level for radiation workers.

X-B. HANDLING PROCEDURES

This instrument was designed with operator safety as a prime consideration. However, as with any piece of potentially hazardous equipment, some general precautions should be observed.

1. Do not operate or attempt to operate the instrument unless you have been authorized to do so.
2. If required by your license or organizational procedures, wear a film badge or other dose measurement device when using or transporting the instrument.
3. While exposure dose levels are well within limits for radiation workers, never expose yourself to the bare source without sufficient reason for justification of the additional dose.
4. Keep all unauthorized persons out of the operating area. A suggested distance is 3 meters (10 feet). The general public must not be unnecessarily exposed to radiation.
5. Maintain security of the instrument at all times. The instrument should be kept in a locked vehicle when transported. When stored, the area should be locked. Not only is it an expensive piece of equipment but, if stolen, could be abandoned under conditions which could be a hazard to the general public.
6. Every user organization has standard operating procedures; the operator should follow those procedures and report any that he feels unsafe.
7. Insure that the gauge has had leak tests performed at the proper intervals, as required by your Radioactive Materials License.
8. If you have any doubts about use of the instrument, ASK. Your Radiological Safety Officer has the answer or can obtain one.

X-C. DISPOSAL

Title 10 CFR, part 20 of the Federal Regulations and Regulations of the Agreement States require that disposition of radioactive materials be accomplished by very restrictive methods.

In general, no licensee shall dispose of licensed material except by transfer to an authorized receipient as provided by regulations. The material may be returned to the factory for disposition or may be sold as an instrument to another licensed user. If the instrument is damaged beyond repair, the source may be transferred to an approved burial facility as provided by Federal and State Regulations.

X-D. SECURITY

Regulations require that locks be maintained on radiographic equipment to prevent accidental exposure of a sealed source when not under the direct supervision of approved personnel. In addition, storage containers shall be physically secured to prevent tampering or removal by unauthorized personnel.

X-E. PERSONNEL MONITORING

The licensee shall not permit any person to use this equipment unless at all times the user is in the possession of the proper form of dosimetry. Dosimetry reports shall be maintained for inspection.

The dosimetry requirement may be waived upon application by the licensee if it can be demonstrated that the waiver is authorized by law and will not result in undue hazard to life or property.

X-F. RECORDS AND REPORTS

1. Each licensee shall conduct a quarterly physical inventory to account for all sealed sources received and possessed under his license. The inventory record shall be maintained for inspection.

2. Each licensee shall have all sealed sources leak tested at intervals not to exceed six months. When a source is transferred and the leak test certification is absent, the source shall not be put into use until it is leak tested.