GOURDIE/FRASER & ASSOCIATES, INC.

NUCLEAR DENSOMETER TRAINING MANUAL

Revised: August 1983

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PART I - Practical, Equipment Operation & Maintenance, and Testing Procedure.

The nuclear densometer is designed to measure the moisture content and density of soils and asphalt. The Soiltest NIC-5DT and Troxler 3401-B provide measurement results through the use of tables, requiring calculations by the operator.

While there is no radiation hazard from "nukes" when following normal recommended procedures, a potential hazard does exist if improperly or carelessly used. Two radioactive sources are housed in the densometer and require special licensing by GFA. In compliance with our license, GFA requires a technician to complete a minimum training course, as follows:

	Duration
1. Radiological Instruction A. Basic Concepts of Nuclear Science B. Measurement of Radiation C. Biological Effects of Radiation D. Radiological Health Requirements E. Emergency Procedures	4 hours min. self study
2. Operating Procedures A. Owners Manual B. Use Logs C. Transporting D. Storage E. Shielding F. Field Use	As required for proficiency, normally 8 hours
3. Examination A. Written - 80% minimum required B. Operational - Demonstrate Proficiency	

A brief description of the equipment you will be using is:

1. Nuclear Densometer Gauge: portable instrument containing electronics, rechargeable battery packs, and radioactive sources.
2. Reference Standard: plastic block used to establish the standard counts (3401B & 3411B); aluminum block used to check standard densities (NIC-5DT).
3. Drill Rod (Pin) and Hammer, or Slide Hammer: used to punch hole for direct transmission requirements.
4. Scraper Plate: functions as a guide for the drill rod, and aids in smoothing test site.
5. Battery Charger
6. Shovel
7. Calculator
8. Copies of appropriate moisture-density curves.

9. Supply of leveling sand and/or No. 10 sieve

10. Regulatory Paperwork
    A. Copy of current radioactive materials license
    B. Copy of daily use log
    C. Copy of manufacturers operation manual
    D. Emergency procedures
    E. Calibration Charts

11. Field Paperwork
    A. Nuclear Field Density Form
    B. Inspection Report Form

In-depth descriptions of the gauges and standards, and their use are found in the operator's manuals, which are considered part of this training manual.

A standard count will be obtained at the beginning of each work day that the Troxler gauge is used. The density standards for the Soiltest gauges will likewise be checked each work day. If an instability with the Troxler gauge is suspected, stability and drift checks will be performed as outlined in the operators manual. If an instability with the Soiltest gauge is suspected, this should be reported to the Director of Engineering.

Testing in the Field

A random, but representative test location will usually be chosen by the inspector, project engineer, owner, or his representative, or the contractor. When testing soil compaction, the technician will usually either know the lab maximum density or will take a representative sample for a Moisture-Density Curve or a Michigan Cone Test.

After the site for the field density is chosen, use the scraper plate supplied to carefully scrape the surface to a smooth condition, removing all dried and loose material. If the scraping action dislodges surface stones, remove them, fill the voids with fine material and lightly tamp the surface. It is best to use native fines to fill voids, but it is acceptable and often easier to use sand. Depth of filler sand should not exceed 1/8 inch. Place the scraper plate on the prepared site - it is important that no voids are present under the plate.

Place one foot on the plate and drive the drill rod into the soil with a hammer (a slide hammer is quicker and easier to drive and retract, if available).

The rod should be driven into the soil at least two inches further than the test depth. Place the gauge over the site so that the source rod lines up with the hole. Insert the source rod down to the desired depth position (six inches for most tests). Seat the gauge firmly so that the source rod is against the side of the hole nearest the center of the gauge. Take and record one or more one minute readings. Note that when using a single count to compute results, the longer time period will yield more accurate tests in the case of the Troxler gauge. The Soiltest gauges use a one-minute count period, so an average of several counts is recommended to improve accuracy.

Situations may occur in which it is impossible to drive the drill rod into the material without destroying the surface. In this case, it may be necessary to use the backscatter geometry (see "Instruction Manual").

Data Calculations

Data calculations should be performed in accordance with the operator's manual for the gauge being used. Note that the procedure for the Soiltest gauges is not the same as for the Troxler gauge.

Trench Measurement

When a gauge is operated close to vertical structures containing hydrogen bearing material, moisture counts may not be valid. Moisture in the side walls of a trench reflect a percentage of neutrons back toward the detector. As a general rule, if the trench wall is closer than 12 inches to any part of the gauge, error in the moisture county can be expected. In trenches four feet or more in width, where the walls contain no more than 15PCF water, no detectable error is expected. When error is expected, there are three alternatives to correcting the problem: 1) widen the trench; 2) take a moisture sample; 3) take a standard count in the trench. Taking a standard in the trench is usually the easiest alternative. With the Troxler, the reference standard is placed at the desired test site and a standard count is taken. The distance from the wall must be the same as the area to be tested. Determine the moisture offset value by subtracting the moisture standard count from the moisture count obtained in the trench. Subtract this value from the moisture count of the test, before dividing by the moisture standard count

In a similar manner for the Soiltest gauges, the difference in moisture density between the daily check test and the trench check test should be used to correct the moisture results. In either case, if there is doubt as to the validity of the moisture results, a sample can be returned to the lab for a moisture content determination, or the "Speedy" moisture tester can be used on site.

Internal Quality Control

A conventional balloon method (Rainhart) density must be taken at a minimum frequency of one per ten nuclear density tests, and not less than one per day per operator per machine. These correlation tests should be taken at exactly the same location as the nuclear test. Depth of the nuclear test should be the same as the balloon correlation test.

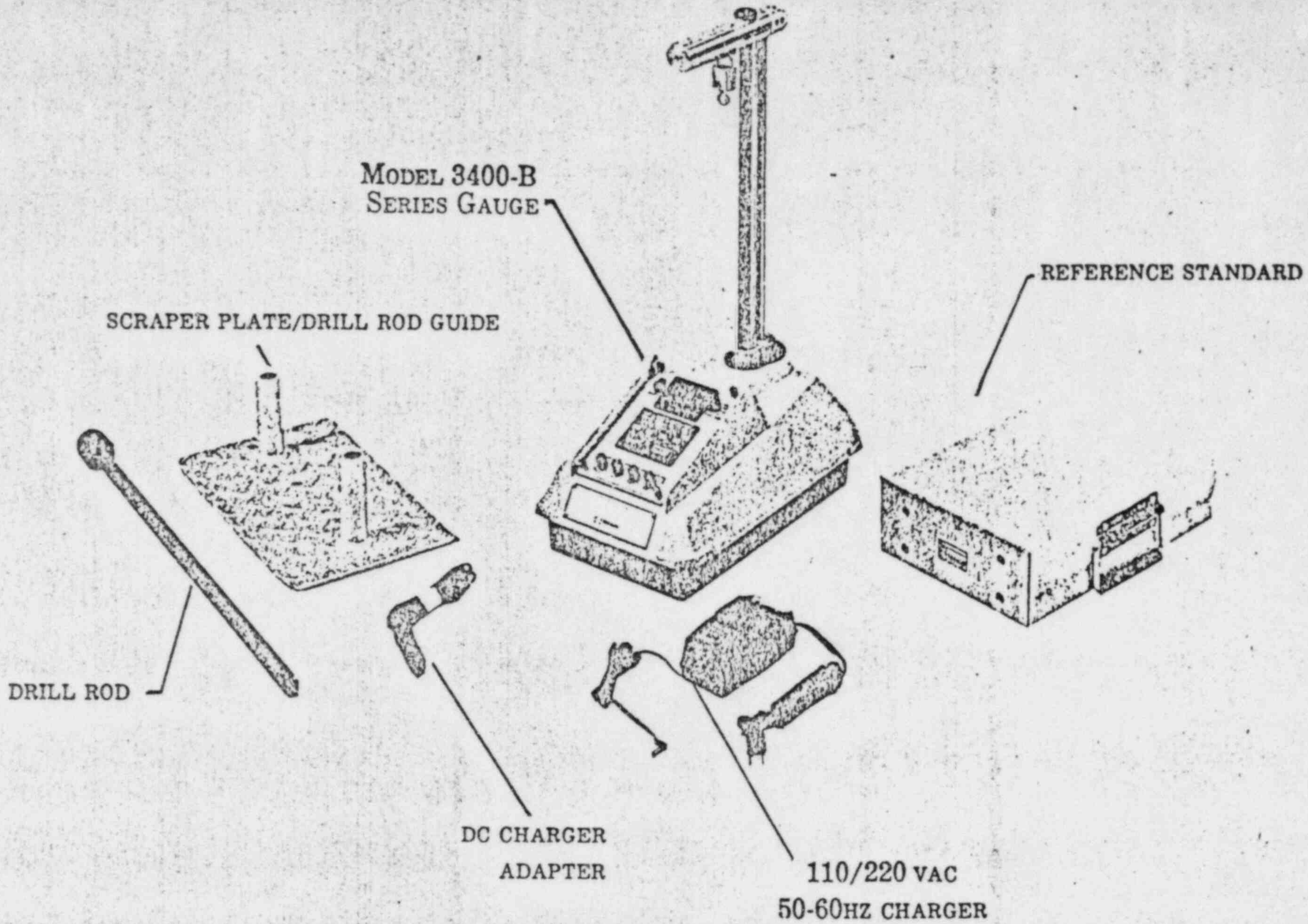
If the wet density of the correlation test does not vary more than three percent, and some are higher and some lower than the corresponding nuclear density, no adjustments are needed. If each of the correlation test densities is more than the corresponding nuclear test and the average exceeds three percent, or if each of the correlation tests densities is less than the corresponding nuclear tests and the average exceeds three percent, the Director of Engineering should be notified.

Expected Testing Error

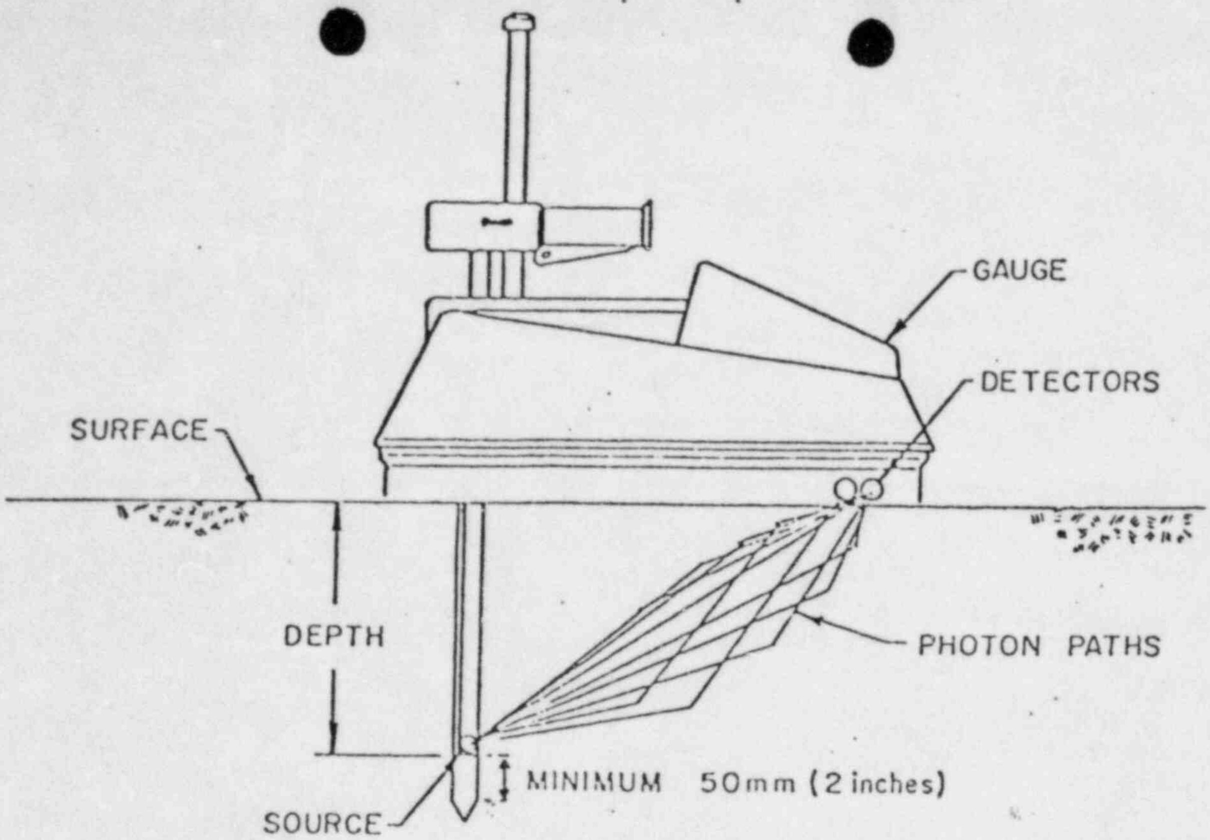
Testing with a nuclear gauge is not a perfect science. There is composition error due to the variation in photon scattering and absorption coefficients of difficult materials; there is surface error due to surface voids between the gauge and the test site; and there is precision error inherent in the statistical limits of the instrument. Fortunately, these errors combined are still minimal. In general, operator-caused errors are the greatest source of testing inaccuracies.

It is essential to keep the keyboards of the nuclear gauges clean and dry. Do not attempt to operate the gauges in the rain. The shutters will require occasional cleaning due to dirt buildup within the shutter chamber. Do not force the source rod handle when the shutter is dirty.

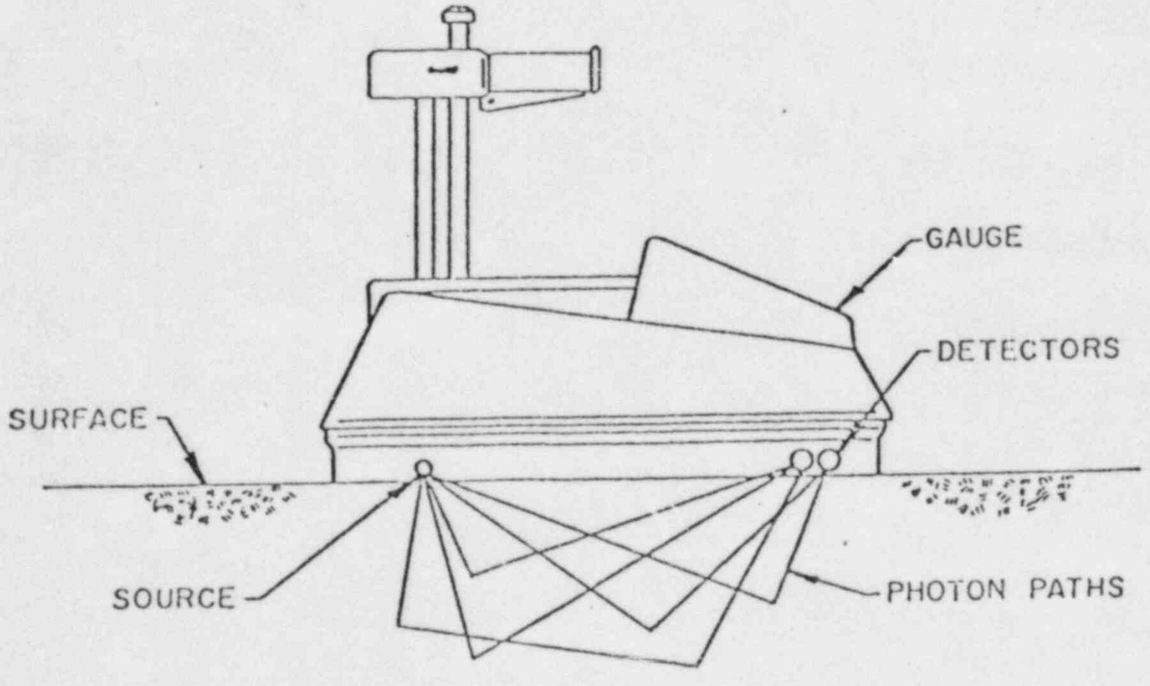
To clean the shutter mechanism of either gauge, set it on its side or tail with the source in the SAFE position. Remove the screws holding the plate assembly. With the base of the gauge facing away from the operator, pry out the assembly. Care should be taken to avoid exposure to the hands. Use a stiff brush to remove all soil and clean the cavity, sliding shield, and bottom plate assembly. Use a silicone spray, preferably a molybdenum disulfide lubricant to lubricate the friction surfaces. Remove all excess lubricant. Do not use oil or grease, as it will accumulate dust and dirt. It may be necessary to clean the source rod - use a long handled brush and then spray with lubricant. Do not handle the source rod, or leave it in the unshielded position for more than a few seconds. Reassemble and check for ease of operation.



3400-B Series Gauge and Accessories



Direct Transmission Density Geometry



Backscatter Density Geometry

PART II - Radiation & Theory of Measurement

Characteristics of Radiation

In certain elements it is found that different atoms of the same element have the same number of protons but vary in the number of neutrons. The number of protons determines the element. Atoms of the same element which have different numbers of neutrons are known as Isotopes. Many of the isotopes are stable, but some are unstable, and therefore, radioactive.

Elements are identified by a one- or two-letter symbol representing its chemical name. The Atomic Number (Z-number) usually preceeds the element symbol, and tells how many protons the nucleus contains which, of course, also equals the number of electrons in orbit. The Atomic Mass Number represents the sum of the protons and neutrons in the nucleus. This is referred to as the A-number and follows the element symbol. Cesium-137 would be shown as $55\ Cs^{137}$.

The ratio of neutrons to protons within the nucleus of the atom determines the stability of the atom. For elements of relatively low atomic weights nuclear stability occurs when the number of protons and neutrons are nearly equal. Heavier elements require a higher neutron to proton ratio for stability. An unstable atom, one with a ratio either too high or too low, will eventually achieve stability by spontaneous emission of energy and/or particles from its nucleus. This process is known as Radioactivity. Nuclear radiation is the product of this process.

The time it takes for half of a given isotope to decay to a more stable atom is referred to as its half-life.

The Curie is the unit used to measure the activity of all radioactive substances. It is the measurement of rate of decay or nuclear disintegration that occurs within the radioactive material. A Curie of any radioactive isotope is the amount of that isotope that will produce 3.7×10^{10} nuclear disintegrations per second which is equivalent to the amount of total radiation emitted by one gram of Radium-226.

The gauges you will be using will have 8 or 10 mCi of Cs-137 and 40 or 50 mCi of Am-241/Be.

The radioactive materials in a nuclear density gauge emit four types of radiation: alpha and beta particles, fast neutrons, and gamma.

Alpha particles consist of two protons and two neutrons traveling at high speed. They are easily stopped by a thin layer of mass.

Beta particles are identical to high speed electrons, traveling at speeds nearly equal to the speed of light. Although the atomic nucleus does not contain free electrons, only protons and neutrons, the electrons which are emitted as beta particles result from the spontaneous conversion of a neutron into a proton and an electron. The neutron which lost or emitted the beta particle has become a proton with a positive charge and thus the atom has been changed.

The alpha and beta emitted by the gauge sources are completely stopped by the walls of the source container. Gamma rays are a form of electromagnetic radiation, as are radio waves and visible light, and are not particulate radiation, like the other three mentioned above. Like all electromagnetic radiation, it exhibits wave phenomenon characteristics, as well as behaving like a particle. It is made up of bundles of energy, called photons, but has no mass and travels at the speed of light. Gamma is of shorter wave length than visible light and is extremely penetrating. The energy of radiation is usually expressed in units of millions of electron volts, or MeV (though in itself, gamma is electrically neutral). The higher the energy, the more penetrating the gamma will be. Gamma radiation is nearly equivalent to the radiation emitted by an x-ray tube (but gamma originates from an isotope; x-rays originate from a tube).

When a gamma ray enters a slab of material, any of three things may happen. First, the photon may be absorbed 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 (sometimes a 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. Note that no residual radiation remains in this material.

Neutrons 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 atoms (such as water or polyethylene).

Theory of Measurement

The Cesium-137 material decays with the emission of a beta particle and is transformed into Barium-137m. The half-life of this decay is 30 years. The unstable barium decays with the emission of a gamma photon, with a half-life of 2.5 min. The beta emission is absorbed by the stainless steel capsule.

The interaction of gamma radiation with matter is very complex. Due to the relatively low energy of Cesium-137, only photoelectric absorption, and Compton scattering need to be considered. In photoelectric absorption, a photon transfers all of its energy to an electron and the electron is ejected from the atom. The electron carries away all of the energy of the absorbed photon, minus the energy binding the electron to the atom. Upon returning to an orbital position in an atom, the electron gives off low energy electromagnetic radiation, usually in the form of heat, which is undetectable in such small amounts. In Compton scattering, a photon collides with an electron, loses some of its energy, and is deflected from its original direction of travel. The photon may experience several of these collisions before being absorbed photoelectrically. This process of radiation absorption results in ionization in the material exposed. Ionization is a process which creates electrically charged particles (ions) from neutral atoms.

Gamma photons interact with the oribital electrons of matter, and since there is a very large quantity of them in relation to the number of atoms, the probability of interaction is very high. On the other hand, neutrons only react to a small degree with the nucleus of the atom. While the nucleus carries a positive charge, the neutron has no electric charge, therefore, it must approach the nucleus much closer than a charged particle to interact.

The Americium-241 material decays with the emission of an alpha particle and a low energy gamma photon. The half-life of this decay is 458 years. The alpha and gamma are absorbed in the stainless steel capsule and lead housing in which the source is embedded. Some of the alphas are absorbed by the beryllium target material, which becomes Carbon-12 upon emission of a fast neutron.

The amount of energy that a fast neutron transfers in a collision is dependent on the mass of the nucleus that is involved: the smaller the nucleus, the greater the energy that can be transferred. As multiple collisions take place, the energy of the neutron is reduced to the point where it may gain as much energy as it loses from further collisions. At this point, the neutron is in thermal equilibrium: this process is referred to as neutron moderation.

The moderation of fast neutrons to thermal energy levels and detection of the thermal neutrons is the means of measurement of moisture content. The ideal situation would be that all thermal neutrons produced within the material be the result of interaction with hydrogen in the form of water. Since this situation does not exist, it is fortunate that other moderating elements and hydrogen not contained in water, are reasonably constant in construction type materials. For construction type soils, boron is the only element likely to be encountered that could cause large errors.

Since the detector response to a unit mass of water is dependent on the distance between them, the measurement is not a true average of the wet material under the gauge, but is an average heavily weighted by the water closest to the detectors. The response is similar in this respect to the backscatter density geometry. In practical application, if the surface of a test site is either wetter than the underlying material because of rain, or dryer because of sun, the moisture content determined will not accurately represent the underlying soil.

The density calibration method used at the factory consists of the accumulation of count rate data on five standard density blocks of known density for determination of density versus count rate computations, and on standard density block to verify calibration accuracy.

Gamma radiation is not always absorbed in direct proportion to the density of the element, as mass attenuation may differ slightly from density.

PART III - Radiological Safety

Principles of Radiation Detection

Radiation cannot be detected by any of the senses - we cannot see, smell, taste, hear, or feel it. Radiological instruments detect radiation by measuring the ionizing effects it produces in some materials. Two methods of measurement will be of interest to us.

The Photographic detection technique is employed in the use of film badges. As a charged particle passes through a photographic emulsion, it will generally cause changes which will result in a blackening on the film when the film is developed. The amount of blackening on the film can be made proportional to the radiation exposure. The film badge requirement for NTL personnel has been waived by the Health Department, due to our low record of exposure.

The fact that gases become an electrical conductor as a result of exposure to radiation is the basis of the Enclosed Gas Volume principle. When radiation causes ionization, ion pairs are created. This produces current which is proportional to the radiation dose rate. This is the principle on which our survey meters, pocket dosimeter, and the gauge detector tubes operate. Our survey meters may be of interest to the reader to help understand quantities of dose rate at varying distances.

Types of Measuring Devices

The types of radiation measuring devices are divided into two basic categories. The first measures the total dose and the second measures the dose rate. The film badge measures the total dose for a given period of time, and the dosimeter measures the total dose for any desired time period.The survey meter measures the dose rate in terms of roentgens per hour.

The film badges available to us are processed monthly and are used to determine the gamma and béta doses for that month. The dosimeter measures gamma dose only, and the survey meter will detect beta and gamma.

Radiation Dose Unit

There are three categories of radiation doses. These are the Exposure Dose, the Absorbed Dose, and the Biological Dose. The Roentgen is a unit of exposure dose of gamma (or x-) radiation as measured in air. Absorbed doses are measured in Rads (Radiation Absorbed Dose). A Rad is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of tissue. The biological dose is measured in Rems (Roentgen Equivalent Man). A Rem is the quantity of radiation of any type that produces the same effects in man as those resulting from the absorption of one Roentgen of gamma (or x-) radiation. Since the absorbed dose is generally small, the millirem is used. (1 REM = 1,000 MREM).

Thus, one Roentgen of exposure of gamma radiation is equal to one REM.

Biological Effects of Radiation

To discuss and understand the effects of radiation exposure we need to define short-term and long-term exposures. A short-term dose of gamma radiation is gamma exposure received over a period of about four days or less. There is little or no body repair during the exposure. A long-term exposure is a gamma radiation exposure received over a period of more than four days. The body has time to begin repairs on the affected cells or tissues.

The following effects are the result of short-term exposure dose of gamma radiation to the whole body:

Actual Dose - REMS	Probable Effect
9 - 50	No obvious effect, except some possible blood count changes.
80 - 120	Vomiting and nausea for about 1 day in 5 to 10% of exposed personnel. Fatigue but no serious disability.
130 - 170	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25% of personnel. No deaths anticipated.
270 - 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20% deaths within 2 - 6 weeks.
400 - 500	Vomiting and nausea in all personnel on first day followed by other symptoms of radiation sickness. About 50% deaths within 1 month, survivors convalescent for about 6 months.

NOTE: Deaths would most likely be from some sickness that the body would normally have thrown off. A cut finger turns into blood poisoning, a cold turns into pneumonia. The body defense mechanism is so busy taking care of damaged cells from radiation that it is unprepared to fight off the other normal insults that occur to the body from day to day.

Some typical routine exposure doses are as follows:

Chest X-ray	100 MREM
Tooth X-ray	10-30 MREM
Commercial jet flight San Francisco to New York	3 MREM
GI Series for Ulcer	2-3 REM

Exposure Limitations

The damage to living tissue is fundamentally caused by the ionizing effects of the radiation. Those cells of the body that are young or actively reproducing are most vulnerable to radiation damage.

In order to protect personnel from overexposure to radiation, the Nuclear Regulatory Commission has established exposure limits for radiation workers. These limits are as follows:

Exposure Limits for Radiation Workers

Type of Exposure	Annual	Quarterly	Weekly
Whole Body: head & trunk, blood forming organs, eyes, gonads	5,000 MREM	1250 MREM	100 MREM
Skin of Whole Body and Thyroid	30,000	7500	577
Hands and Forearms, Feet and Ankles	75,000	18,750	1,442

You will note that the maximum permissible long-term dose is well below the exposure doses which will have detrimental effect on the human cells or tissue.

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

Protection Against E posure

There are three basic ways in which a person can protect himself from radiation exposure: time, distance, and shielding.

As a person decreases the time of exposure to a given radiation dose rate, total dose is reduced in direct proportion.

As a person increases distance from the radiation source, the dose rate falls off sharply. Radiation obeys the "inverse square law," which states that the radiation intensity decreases as the inverse square of the distance from the source to the subject. As a person moves from one foot to two feet from a source, the intensity is reduced to one-fourth.

$$\frac{I_1}{I_2} = \frac{D_2^{\,2}}{D_1^{\,2}}$$

I_1 - initial intensity, D_1 - initial distance
I_2 - final intensity, D_2 - final distance

And thirdly, as shielding between a person and the source is increased, dose rate (or intensity) is decreased. Of course, the thicker and denser the shielding material, the more protection it provides. The internal tungsten shield provided in the Troxler produces a reduction of gamma dose rate on the surface of approximately 50 to 1.

Neutron sources are very difficult to shield internally. Use of high hydrogen moderators in the gauge would provide shielding, but would also reduce the measuring capacity of the gauge. The neutron dose rate is kept within reasonable levels by simply limiting the neutron yield of the source.

Under average conditions, a full time operator working a 40-hour week can expect to receive about 4 mrem per week for his whole body and 6 mrem for his hands and feet. This dose is only 4% of the maximum recommended level for radiation workers.

Handling Procedure

The following are some precautions an operator should observe:

1. Do not allow any unauthorized personnel to operate or handle the instrument. Keep all unauthorized persons away from the operating area.

2. Keep the source position in the "SAFE" position when not in use.

3. Never expose yourself to the bare source if at all avoidable.

4. Maintain security of the instrument at all times. When left unattended the source should be locked. When in transit, if you leave the vehicle, lock the gauge inside the cab. If the instrument is to be stored at a construction site, receive authorization from your lab supervisor, and lock the instrument to a stationary object where it cannot be removed.

The best radiation protection program of all is a concentrated effort at maintaining the maximum distance from the source at all times. When cleaning the device use the body of the gauge as a shield between you and the exposed source; work as fast as possible; and do not handle the exposed source if at all possible. When in the field, keep the curious away, but do not make such a big thing of it that people are frightened.

Records Requirements

GFA is required to conduct a quarterly physical inventory to account for all sealed sources. We are required to perform sealed sources leak tests (or wipe tests) every six months. The purpose of the leak test is to determine the amount of removable radioactive material, which should be none provided the source containers are not damaged.

A daily use log is provided with each densometer. The operator must fill this out after each use.

Emergency Procedures

Report any severe damage, theft, or loss, of a gauge to the Radiation Protection Officer immediately. In the event of an accident resulting in severe damage to the gauge, our first concern is to prevent the possibility of radioactive materials from escaping to the environment, resulting in radioactive contamination. The source material is encapsulated in two stainless, welded containers, which is further securely mounted into the gauge enclosure. It is highly unlikely that the material could escape in the event of a severe accident or fire, but the operator must be prepared for this possibility. The first action in the event of an accident is to keep all other people away from the site, and stop all vehicle travel in the area of the accident. Cordon off the area and enlist the assistance of the contractor to maintain security in the area. If damage is visible or expected, do not move the instrument. Call the Radioation Protection Officer, Joe Elliott , at 1-616-946-5874 or 947-6449 evenings or weekends. Upon assessing the situation, he will direct you as to what to do.

Storage

At the end of each work day, all of the nuclear gauges will be stored in an enclosed area designated as a storage area for that purpose. The radiation level at 6 inches from this enclosure shall not exceed 2 mr/hr. These storage areas must be maintained under lock and key to prevent unauthorized use or removal of gauges.

Transporting

During the transportation of the nuclear gauge, the device must be secured within the vehicle as far away from the passenger compartment as practical. All transportation activity must comply with the requirements of 10 CFR Part 71 and DOT regulations. A specific "Transportation Information" sheet must accompany any gauge leaving the confines of our facility.

If shipping is by common carrier a signed shipper's certificate must accompany the device, and be submitted to the carrier (in addition to the Transportation Information sheet). For more specific procedure, see the Manufacturer's Manual. Copies of all shipping certificates must be kept on file at the originating office and at the Boise office.

It is the responsibility of the individual to maintain security for control of the radioactive materials. Individuals must never leave gauges unattended (see page 15).

Special Maintenance

Any maintenance on gauges which involves removal of source rods must not be performed by GFA personnel and must only be performed by the gauge manufacturer.