THE TERRACON COMPANIES, INC.

RADIATION SAFETY TRAINING
FOR
NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS

THE TERRACON COMPANIES, INC.
16000 COLLEGE BLVD.
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This manual has been developed to train Terracon employees in the safe use of nuclear density/moisture gauges. The contents of this manual will be presented to prospective nuclear density gauge operators in a 10-hour classroom presentation. Course materials contained in this manual will be supplemented by hands on demonstrations including a calibration workshop and a field exercise.

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This course will be followed by a one hour examination to include hazardous materials transportation requirements in accordance with U.S. DOT HM-126. Candidates who successfully complete the test with a score of 80% or higher will be issued a Certificate of Completion. Terracon personnel who fail the examination will be required to repeat the course and retake the examination until a passing score of 80% is obtained.

A. PRINCIPLES OF RADIATION

1. Atomic Structure

What exactly *is* radiation? In order to understand what radiation is and where it comes from, it is first necessary to understand a little about the structure of matter. All matter in the universe is composed of basic building blocks known as **atoms.** Atoms, in turn are made up of smaller, "sub-atomic" particles.

Every atom is composed of a nucleus at it's center, and **electrons** which travel in various orbits around the nucleus. The orbit in which an electron travels is dependent upon its energy level. The various energy orbits in which electrons may travel are referred to as "**shells**."

The nucleus of an atom (the atomic nucleus) is composed of positively charged particles called **protons**, and may also contain **neutrons**. Neutrons have no electrical charge. A summary of atomic particles appears below.

Proton A particle having a single positive (+) electrical charge. It is a relatively heavy particle with a mass of approximately one atomic mass unit (AMU).

Neutron A particle with approximately the same size and mass as the proton. It has no electrical charge (neutral).

Electron A negatively charged particle (-) in orbit around the nucleus. The electron is extremely light weight as compared to the proton or neutron (about 1/1840 AMU).

As everyone is aware, there are many kinds of matter with many different properties. There are gases, liquids, heavy solids, light solids, etc. The properties exhibited by any type of matter is determined by the number of protons, neutrons and electrons the atoms of the matter contain. There are over 100 different kinds of basic atoms, or **elements**, known to man. Some of the more commonly known elements are oxygen, hydrogen, lead, aluminum and sulfur.

As we have said, the nucleus of an atom consists of protons and neutrons (except for hydrogen, the simplest atom, which has no neutrons). The number of protons in the nucleus determines the type of element the atom is. Since each atom of an element has a specific number of protons in the nucleus, we can use this **atomic number** (also called a Z number) to identify the element. While the number of protons in the nucleus of each atom of a given element is constant, the number of neutrons may vary. Although the atoms with more or less neutrons retain the same chemical properties, their **atomic weight** will vary. (Atomic weight = the mass of protons + neutrons).

Atoms of the same element having different numbers of neutrons are called isotopes. All matter in the universe is composed of around 800 isotopes Approximately 300 of these isotopes are stable, while the remaining 500 are unstable, or **radioactive**. Isotopes that have the same number of neutrons and protons tend to be naturally stable. Isotopes with more neutrons than protons tend to be unstable. An usable isotope seeks to become stable, that is, it attempts to

reach a stable ratio of protons and neutrons, giving up energy in the process. This process by which unstable isotopes become stable is called **"radioactive decay"** or **"disintegration".** Radioactive decay results in the emission of alpha particles, beta particles, neutrons and/or gamma rays from the nucleus.

2. Types of Radiation

Radiation emitted by an atomic nucleus is of two main types: **particulate radiation** and **electromagnetic radiation**. As may be apparent, particulate radiation is composed of sub-atomic particles which move through space, while electromagnetic radiation consists of high energy electromagnetic waves which have no mass or charge. Particulate radiation consists of either alpha or beta particles which are classified as follows:

Alpha particles are essentially helium nuclei. They consist of two protons and two neutrons and have an atomic weight of 4. Alpha particles travel slowly, and carry a positive charge. Alpha particles can travel only a few centimeters in air and can be stopped by a sheet of paper.

Beta particles are high speed electrons. They have a range of several feet in air, and can be stopped by a few sheets of paper.

Neutrons Neutrons that are freed from the atomic nucleus. They have mass but have no charge. They are very high energy, penetrating particles. A neutron may pass entirely through the body without being stopped. Neutrons are stopped by several feet of water or specialized concrete.

Electromagnetic radiation may be described as small packages of energy called photons or quanta. The energy of electromagnetic radiation is dependent upon both frequency and wavelength. High frequency, short wavelength radiation has a low energy level. The higher the energy level, the greater the penetration ability of the radiation. The types of electromagnetic radiation employed in industrial radiography are **X-rays** and **gamma rays**. X-rays are the same as gamma rays and differ only in their point of origin. Gamma rays are emitted due to radioactive decay process which occur in the atomic nucleus, while x-rays are released by changes in the orbital paths of electrons. Gamma rays can travel hundreds of feet in air and are stopped by lead or thick concrete.

The radioactive material used in nuclear density/moisture gauge sources produce all four types of radiation. Alpha and beta particles are stopped by the stainless steel capsule surrounding the radioactive material. The gamma and neutron radiation which escape the stainless steel capsule and those used by the devices to take measurements of density and moisture content of construction materials. These are also the two types of radiation against which authorized gauge users must learn to protect themselves.

3. Radioisotopes

Radium and uranium are examples of two naturally occurring radioactive isotopes. A number of additional radioactive isotopes (**radioisotopes**) have been created by man since the 1930's. Man-made radioisotopes are produced in nuclear reactors by one of two methods: fission and neutron bombardment. **Fission**, the splitting of heavy elements into lighter elements, produces

fragments of "by-product" radioisotopes such as Americium 241. **Neutron bombardment** creates radioisotopes by firing a stream of neutrons at atoms of an element. The radioisotope is created when the nucleus of the bombarded atom captures neutrons. This process of creating radioisotopes is called **activation.** The atoms of these radioactive isotopes are in an excited or unstable state and contain excess energy. The excess energy is emitted in the form of radiation as the atoms attempt to become stable. Again, the process of the atom emitting energy to become stable is known as radioactive disintegration or radioactive decay.

The radiation emitted in the decay process usually takes the form of alpha or beta particles and gamma rays. Usually, when a radioactive atom emits an alpha or beta particle, there is an associated energy adjustment in the atom in the form of emission of gamma rays. The rate of radioactive decay of a radioisotope is usually expressed in terms of its **half-life**. The half-life of a radioisotope is defined as the length of time required for one-half of the radioactive material present at a given time to decay or disintegrate.

Each radioisotope will decay according to a characteristic pattern which is distinctive for that particular isotope. No other isotope will follow the same decay pattern.. Figure 1 lists characteristics of some of the more commonly used radioisotopes.

FIGURE 1

Isotope	Half-Life	Gamma Energy in MeV	Average Energy Level	Dose Rate Rhf/Ci	Dose Rate Rhm/Ci
Iridium 192	75 days	12 Gammas 0.137 to 0.651	0.4 MeV	5.9	0.55
Cobalt 60	5.3 years	2 Gammas 1.17 & 1.33	1.2 MeV	14.5	1.35
Cesium 137	27 years	0.66	0.66 MeV	3.5	0.32
Thorium 170	127 days	2 Gammas 0.052 & 0.084	0.07 MeV	0.027	0.0025

4. The Curie

Each transformation of an unstable atom into a stable one is called a "disintegration." The amount of **radioactivity** in a given source is measured in terms of the number of atomic disintegrations per second. The **Curie** is the unit of measure of radioactivity. A source is said to have an **activity** level of one Curie when it is disintegrating at the rate of 37 billion (3.7×10^{10}) atoms per second. The Curie was established based on the decay rate of one gram of Radium. In addition to radioactive atoms, a radioactive element may contain stable atoms, either because of incomplete activation or because some atoms have already decayed. There may also be impurities in the material.

Because of the presence of stable atoms and impurities, the radioactivity of a substance is often measured as the amount of activity per gram, or **specific activity**. Specific activity is usually expressed in Curies per gram of material. A radioactive isotope with a high specific

activity permits the use of a smaller volume of material to obtain a given curie strength than the same type of a radioisotope having a low specific activity.

5. Attenuation of Gamma Rays

Gamma rays emitted by radioactive decay may be absorbed by any number of materials. Although the gamma rays may be diminished by any given absorber, not all of them will be stopped. Because it is not practical to attempt to compute the thickness of shielding required to stop gamma radiation completely, the amount of shielding required to stop one-half of the radiation is typically used. This thickness is referred to as the **half-value layer**.

The half-value Layer (HVL) is defined as that thickness of material required to reduce the radiation intensity to one-half its original intensity. The thickness of material which will reduce the radiation intensity to one-tenth (1/10) its original intensity is referred to as the TENTH-VALUE LAYER (1/10 VL).

Figure 2 shows half and tenth value layers for common shielding materials with various isotopes.

FIGURE 2

SHIELDING MATERIAL IN INCHES	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
STEEL	2.90	0.87	2.0	0.61	2.25	0.68
CONCRETE OR ALUMINUM	8.6	2.6	6.2	1.9	7.1	2.1

Approximate Gamma Ray and Half and Tenth Value Layers

6. Units of Radiation Measurement

In the preceding section of this manual, it was stated that the principal unit of measure of radioactivity of a source is measured in Curies. The Curie, as you will recall, is equal to the number of atomic disintegrations per second in one gram of Radium.

The units commonly used to measure the energy of the radiation emitted from these atomic disintegrations are as follows:

ROENTGEN. The unit for measuring external radiation exposure is the roentgen, named after the man who discovered the x-ray. The Roentgen in typically abbreviated as "r." The Roentgen is used to measure the energy of gamma or X-ray radiation *in air*, and is defined as the quantity of radiation that will produce one electrostatic unit (esu) of charge in one cubic centimeter of air.

For the purposes of radiation protection, the effect that radiation has on the human body is of primary concern. Since the Roentgen measures radiation in air only, it cannot be used to measure the biological effects on the human body.

RAD (Radiation Absorbed Dose) is another unit of measurement for radiation absorbed by matter. The RAD is defined as the amount of radiation energy imparted to matter per unit mass of irradiated material. Although this unit considers the effects of various forms of radiation on matter, it does not specifically associate the radiation to its effect on living tissue. The unit of measure used to associate a given radiation dosage to its effect on the human body is called the **rem.**

REM (Roentgen Equivalent, Man) The rem is defined as the quantity of ionizing radiation of any type which, when absorbed by man or any other mammal, produces a physiological effect equivalent to that produced by the absorption of one roentgen of X-rays or gamma rays.

It is known that different types of radiation, (i.e., alpha, beta, gamma, neutron and x-ray) can have different effects on the human body. For this reason, the various types of radiation are assigned a **Quality Factor**, also known as an RBE (relative biological effectiveness). The rem unit is essentially the rad multiplied by the Quality Factor. The Quality Factors for each type of ionizing radiation are presented below. As may be apparent, the higher the Quality Factor, the more biologically harmful the radiation is to man.

Radiation Type	Quality Factor
X-ray, Gamma Ray	1
Beta Particles	1
Neutrons, slow	5
Neutrons, fast	10
Alpha Particles	20

By using the rem to measure personnel radiation exposures, the Quality Factor is already built in to the measurement. Most cheap radiation survey meters are scaled in Roentgens and only read gamma and beta radiation. Because the quantity factor for both gamma and Beta particle radiation is 1, the reading from such meters may be directly translated into **rem.**

B. BIOLOGICAL EFFECTS OF RADIATION EXPOSURE

1. Relative Risk of Occupational Radiation Exposure

Shortly after the discovery of radioactive materials, their effect on human health became apparent. Madame Curie, the discoverer of Radium, routinely handled her discoveries in an unshielded condition, and eventually died of radiation poisoning. The effects of the atomic bombs dropped on Japan and the more recent effects on people affected by the Chernobyl nuclear disaster have created a vivid mental image of the potential dangers of radiation. Due to graphic images these tragedies have generated, and numerous science fiction novels and movies, the general public tends to regard radiation with fear and to have an exaggerated concept of the potential hazards of all forms of radiation.

Depending on the type and magnitude of radiation exposure, the biological effects of radiation can be serious, even deadly. However, when handled properly in limited quantities, radiation can be made to safely perform many useful services. Ignorance of radiation hazards generally results in one of two attitudes, both of which may prove detrimental to the safe use of radioactive materials. The first is a blind, irrational fear of radioactivity and the second is complete lack of appreciation for potential radiation hazards.

Daily living involves many health hazards as great or greater than low level radiation. Consider the potential hazards inherent in driving automobiles and using electricity. The hazards of both of these everyday activities are recognized and appropriate safety measures are taken to minimize the risk to the public. This is precisely the attitude which must be assumed toward the beneficial uses of radioactive materials. The table below compares occupational exposure to low-level radiation to other every day risks to health.

Estimated Loss of Life Expectancy from Health Risks

Health Risk	Estimate of Life Expectancy Lost(Average)
Smoking	6 years
Overweight by 15%	2 years
Alcohol consumption (Avg. U.S. consumption)	1 year
All accidents combined	1 year
Motor vehicle accidents	207 days
Home accidents	74 days
Drowning	24 days
All natural hazards (lightning, earthquake, flood, etc.)	7 days
Medical radiation	6 days
Occupational radiation exposure	
300 millirems/yr from age 18 to age 65	15 days
1 rem/yr from age 18 to age 65	51 days

From: US Nuclear Regulatory Commission, Regulatory Guide 8.29, February 1996

Persons working with density/moisture gauges must keep themselves knowledgeable about developments in radiation safety practices and regulations. Most of the effects of radiation on the human body are known and predictable. Radiation safety practices are based on these effects, and on the characteristics of the radiation being used.

2. Naturally Occurring Radiation Sources

It has been estimated that humans are exposed to 100 to 200 millirems (0.2 rem) of radiation per year from naturally occurring sources. Cosmic radiation from outer space is ever present. Also, the earth's crust contains many radioactive elements which find their way into building materials, foods, clothing, and many other items for human use. When radiation for medical reasons is included, it can be seen that humans can and do tolerate considerable radiation

during the course of a lifetime. Some examples of radiation dosage received from various daily activities are presented below.

APPROXIMATE RADIATION EXPOSURE FROM NATURAL SOURCES

Radiation Source	**Annual Dose** (millirems)
Cosmic Radiation (Radiation from the sun and other celestial sources. Most cosmic radiation is blocked by the Earth's atmosphere. Natural cosmic radiation increases approximately 1 millirem for every 100 feet of elevation above sea level.)	
At Sea Level	**44 mrem**
Denver, CO	**97 mrem**
Earth (From natural radioactive materials present in the Earth's crust from which common materials are produced)	
From Ground Surface	**15 mrem**
Living in a Stone House	**50 mrem**
Living in a Brick or Concrete House	**45 mrem**
Living in a Wood House	**35 mrem**
Man-Made Radiation	
Fallout from Past Weapons Use/Testing	**4 mrem**
Medical X-rays	**10 -- 200 mrem/test**
Daily Living	
Eating/Drinking/Breathing	**25 mrem**
Television (2 hrs/day)	**0.3 mrem**
Air Travel (3000 mile trip)	**2 mrem**

3. Physiological Effects of Radiation Exposure

The effects of radiation on living tissue is due largely to the process known as **ionization**. When x-rays, gamma rays and sub atomic particles (alpha, beta and neutrons) interact with living materials such as the human body, they may deposit enough energy to cause biological damage. Radiation can cause several different types of events such as the very small physical displacement of molecules, the changing of a molecule to a different form or ionization, which is the removal of electrons from atoms and molecules. Ionizing radiation can result in mutations in DNA and in the nucleus of cells . Neutrons, alpha and beta particles and electromagnetic radiation as least as strong as x-rays can induce ionization of living tissues.

The effect of continual exposure to small amounts of radiation can be very subtle, producing no apparent change in the health of the individual, but perhaps changing the genes so as to cause

mutations in later generations. Just how much radiation can cause this kind of damage is the subject of discussion between many disciplines in the scientific community. It may be safely assumed, however, that if the present NRC requirements are met, no appreciable genetic change will be observed when the individual effect is considered in the population as a whole.

A person receiving radiation injury exhibits symptoms according to the severity of his exposure. Examples of potential injury from what are considered mild to moderate radiation exposure levels are presented in the following table.

Effects of Acute Radiation Doses (Whole Body Dose Within A 24 Hour Period)

Mild Dose 0-25 rem	An exposure of this magnitude may not result in any obvious injury. Above 5 rem there would probably be some changes noted in blood.
Moderate Dose 25-200 rem	An exposure of this magnitude would result in observable effects.
25-50 rem	Definite blood changes, no serious injury
50-100 rem	Some injury, no permanent disability
100-200 rem	Probable injury, some disability

Recovery from moderate doses of radiation is likely unless complications related to overall poor health, additional injuries, or infections set in. However, delayed effects of moderate doses may shorten life expectancy as much as one percent. The potential biological effects of extreme radiation doses would be expected to occur as follows.

Median Lethal Dose 200-600 rem	An exposure of this magnitude would be fatal to 50 percent of those exposed.
200-400 rem	When dosages exceed 200 rem, symptoms increase to include hair loss, loss of appetite, sore throat, pallor, diarrhea, and moderate emaciation. These symptoms occur after a latent period of about one week (sometimes longer). Death is possible.
400-600 rem	Injury and disability are certain at these exposures. Symptoms include nausea and vomiting in one to two hours, followed by a latent period of perhaps as long as a week. After this period hair loss, loss of appetite, and general malaise accompanied by fever, are characteristic. Severe inflammation of mouth and throat usually occurs near the third week. The fourth week brings on pallor, generalized sores, diarrhea, nose bleed, and rapid weight loss. General disability may be accompanied by drastic changes in the blood picture, including abnormalities in the red and white cells, platelets, and hemoglobin. It is also probable that intractable anemia will develop, that sterility will result, and that cataract formation will take place.

Lethal Dose
600-800 rems

An acute exposure of 600-800 rem or more to the whole body of man is considered a lethal dose. Symptoms are nausea and vomiting in one to two hours, then a short latent period of about a week following which there is diarrhea, vomiting, and inflammation of mouth and throat. As early as the second week, fever and rapid emaciation occur with the probability of death.

Estimated Doses for Varying Degrees of Injury

DOSE RATE	PERIOD OF TIME	EFFECT
500 R/day	2 days	Mortality close to 100%
100 R/day	Until death	Mean survival time 15 days, 100% mortality in 30 days.
60 R/day	10 days	Morbidity and mortality high with crippling injuries.
30 R/day	10 days	Disability moderate.
10 R/day	365 days	Some deaths.
3 R/day	Few months	No drop in efficiency.
0.5 R/day	Many months	No large scale drop in life span.

As may be seen in the table above, the magnitude of the dose and the period of time over which it is received have a significant effect on the potential for radiation injury It is much less injurious to receive numerous small radiation doses over time than to receive a large exposure in a short period of time.

4. Detection and Measurement of Radiation

The human senses cannot detect radiation coming from a radioactive source. The body may be penetrated by high intensity radiation and feel no pain, even though it may be severely injured by the radiation. Just as overexposure to the ultraviolet radiation from sunlight may not be realized until a sunburn later develops, a person receiving an overexposure of radiation may not be aware of it until some time later when radiation sickness begins to develop

Because we are unable to detect the presence of potentially harmful radiation, we must depend on some kind of instrument to detect radiation that may be danger.

The term "**detection**" usually includes only a determination that radiation is present, while "**measurement**" includes some determination of the amount of radiation present.

Radiation measuring instruments usually provide a measurement of **dose** or **dose-rate**. Dose measurement refers to the accumulated radiation exposure over a period of time. A dose-rate measurement refers to the intensity of radiation in unit time. Dose-rate measurements are typically scaled in millirems (1/1000 or a rem) per hour, or **mrem/hr**.

One instrument that is used to measure accumulated dose is the **film badge.** The typical film badge consists of a small film holder equipped with thin lead or cadmium filters, in which a special x-ray film is inserted. The film badge is designed to be worn by an individual when in radiation areas or when using a radiation device such as a nuclear/density moisture gauge. After a given period of time, typically a month or in some cases a calendar quarter (three months) the film is removed and shipped to a processing service where the film is removed and analyzed. The density of the processed film is proportional to the radiation received. The film badge service will use a densometer to measure and compare the density of the film to a set of control films. Through this comparison, the service estimates the amount of radiation received by the individual who wore the badge.

A second instrument which measures radiation dosage is the **pocket dosimeter**. Pocket dosimeters resemble a fountain pen. Each contains a quartz fiber within an air chamber, a lens for viewing the quartz fiber and a calibrated scale markings. Exposure to radiation causes the quartz fiber to change position similar to a needle on a gauge. The position of the quartz fiber is compared to the calibrated scale markings allowing a direct visual reading of approximate accumulated radiation dosage received. The most common range used for personnel dosimetry is 0-200 mr.

An instrument which measures dose-rate is the **Radiation Survey Meter.** Of the various types of survey meters, the most useful type is the ionization type dose-rate meter. Dose-rate survey meters contain relatively large ionization chambers similar to those in the pocket dosimeter. They also contain a compact amplifier system with self contained batteries. The dose-rate survey meter tends to be a small, lightweight unit an excellent response to a wide range of radiation from low energy to high energy. These instruments are typically accurate to within +/- 10% of the reading. The most popular standard type is characterized by its ruggedness and fast response to radiation. However, its lower limit of detection is approximately 1 or 2 mr/hr..

The other type of ionization meter typically employed to measure radiation dose-rate is the "**thin window**" ionization chamber variety. These instruments usually can measure small radiation levels to as low as 0.1 mr/hr , as well as much higher levels. Although more accurate at low energy levels, these instruments tend to be more expensive than the typical survey meter and require much more delicate handling.

Geiger Counter type instruments, in spite of their great sensitivity, usually are not recommended for the precise measurement of radiation because of their energy demands. However, units of this type are used in automatic monitoring and warning systems. Below a preset level, usually about 2 mr per hour, one type of instrument will indicate "safety" by a green light. Above this level, a red flashing light will be actuated. Alarms and door interlocks can be actuated with the warning light. These units are the best available systems for preventing exposure to high energy incidents, such as those which could happen in a nuclear power plant, but are not practical for field operation and are not considered essential for use with low level sources.

5. Principles of Protection Against Radiation Exposure

The operation of moisture/density gauges require the use of radiation sources. Unless adequate radiation safety precautions and procedures are developed, understood by individual gauge users and adhered to in the field, radiation overexposures can occur.

There are three basic principles employed in protection against radiation. They are **Time**, **Distance**, and **Shielding**. Each of these principles must be employed to ensure that radiation exposures of authorized nuclear density/moisture gauge users are kept **As Low as Reasonably Achievable (ALARA)**.

Time

The radiation dose received by and individual is directly proportional to the **time** spent in the **radiation field**. A person in a radiation field for a short period of time obviously will receive less of a dose than one remaining in the same field for a longer period of time. When the operator is using a radioactive source, he/she is in the radiation field. The strength, or dose-rate of that field is measured in millirem/hr. For a given dose-rate and time in the field, the operator will receive a dose.

Dose = Dose-Rate x Time Exposed

For example, the body dose-rate while carrying a nuclear density/moisture gauge is approximately 0.5 mrem/hr. If the operator carries the gauge 20 times per day, 5 days a week for approximately 20 seconds at a time (total of 1/2 hr/week). What is the dose for the week?

Dose = Dose Rate X Time Exposed
Dose = 0.5 mrem/hr X 0.5 hr/week
Dose = 0.25 mrem/week

This is less than one half of 1% of the maximum permissible radiation exposure limit of 100 millirem/week permitted under federal NRC guidelines. (NRC permissible radiation exposure levels will be discussed in more detail later in this presentation.) Limiting the time of potential exposure is one method to maintain the radiation dose received as low as reasonably achievable (**"ALARA"**).

Distance

Much like the light being emitted by a flashlight, radiation starts from a point source and spreads out as the distance from the source increases. The intensity of the radiation at any distance from the source thus decreases in accordance with the **inverse square law**. Simply put, doubling the distance will reduce the radiation dose-rate to one fourth (1/4) the original intensity. Conversely, reducing the distance by one half will increase the radiation dose rate by four (4) times.

Given the intensity or dose-rate at any distance, the dose-rate at another distance can be calculated as follows:

Inverse Square Equation
$I_1 X (D_1)^2 = I_2 X (D_2)^2$

EXAMPLE:
If the dose-rate at one meter from a 10 millicurie source is 3.3 mrem/hr, what is the dose-rate at 10 meters?

$I_1 X (10)^2 = 3.3 X (1)^2$

$I_1 = 0.033$ mrem/hr at 10 meters

As may be obvious from this discussion, increasing the distance between yourself and the radiation source can reduce the radiation dose-rate received.

Shielding
As previously mentioned in the discussion of half and tenth-layer values, gamma and neutron radiation cannot be completely stopped by shielding, but can be attenuated (reduced). Dense elements (those with high atomic numbers) such as tungsten and lead provide the most effective radiation shielding. As previously indicated, the half-layer thickness of a material is that thickness required to reduce radiation of a given energy radiation by one half. Half-layer values of lead and concrete which are required to reduce the radiation of a 10 millicurie Cs-137 gauge source by one half are as follows:

Lead = 0.25"
Concrete = 2.25"

6. Maximum Allowable Radiation Dose Limits

Annual radiation dose limits as established by the U. S. NRC are as follows:

Adult workers over the age of 18 are permitted **5 rems (5,000 millirems)** for the total effective dose equivalent, which is the sum of the deep dose equivalent from external exposure to the whole body and the committed effective dose equivalent from intakes of radioactive material. Since the radioactive materials used in nuclear density/moisture gauges are contained in sealed capsules, there will be no intake of radioactive material resulting from their use. Exposure from nuclear density/moisture gauge use will be entirely from external exposure.

15 rems for the lens dose equivalent (LDE) which is the external dose to the lens of the eye.

50 rems for the shallow dose equivalent (SDE) which is the external dose to the skin or to any extremity.

The 5 rem occupational dose limit for adult workers is based on consideration of the potential for delayed biological effects. The 5 rem limit, together with the application of the concept of keeping occupational doses as low as reasonably achievable (ALARA), provides a level of risk of delayed effects considered acceptable by the NRC. The limits for individual organs are below the dose levels at which early biological effects are observed in the individual organs.

Minors (< 18 years old) are allowed one tenth the adult occupational dose limit or 500 millirems per year.

For the protection of the embryo/fetus of a declared pregnant woman, the dose limit is 0.5 rem during the course of the pregnancy. The dose limit for the embryo/fetus of a declared pregnant woman is based on a consideration of the possibility of greater sensitivity to radiation of the embryo/fetus and the involuntary nature of the exposure. In order to be subject to the lower exposure limits, a pregnant woman must notify her employer of her pregnancy in writing.

Exposure to members of the general public must be maintained below 100 millirems in a year or 2 millirems/hr.

Some workers fear sterility or impotence as a result of normal occupational radiation exposure. However, the NRC and international health authorities have established that there is a threshold below which such effects do not occur. Temporary or permanent sterility cannot be caused by radiation at the levels allowed under NRC limits. Acute doses on the order of 10 rem to the testes can result in a measurable, but temporary, reduction in sperm count. Temporary sterility (suppression of ovulation) has been observed in women who have received acute doses of 150 rads. The estimated acute exposure threshold for inducing permanent sterility is about 200 rads for men and about 350 rads for women. These doses are far greater than the NRC's occupational dose limits for workers.

For 1993, the NRC received reports on about a quarter of a million people who were monitored for occupational exposure to radiation. Almost half of those monitored had no measurable doses. The other half had an average dose of about 310 millirem for the year.

7. Radiation Exposure of Nuclear Density/Moisture Gauge Users

The nuclear density/moisture gauges utilized by Terracon each contain two radioactive sources. One source contains **10 millicuries** of **Cesium 137 (Cs-137)** and the second source contains between 40 and **50 millicuries** of **Americium 241 (Am-241).** Both radioisotopes are by-product materials formed in nuclear reactors. The amount of radioactive material in each source is extremely small and is contained within an hermetically sealed stainless steel capsule approximately the size of a thimble. The stainless steel capsules containing the radioactive material are very strong and are capable of withstanding temperatures of up to 2500° F without deterioration.

The Americium 241 and Cesium 137 contained in the sealed sources each emit all four types of radiation previously discussed, alpha and beta particle radiation, gamma rays and neutrons. However, the alpha and beta particle radiation is completely stopped by the sealed stainless steel capsule surrounding the radioactive material. Therefore the only radiation of concern to the user is gamma and neutron radiation.

Of the two sources present in the nuclear density/moisture gauges used by Terracon, the Cs 137 source in the tip of the probe rod emits gamma rays, which are used in density determination of soils. The Am 241/Beryllium source emits neutrons, which are used to calculate the moisture content of soils. The Am241 material is a compacted mixture of Americium oxide and beryllium metal. The pellet of radioactive material is fusion welded into

two separate stainless steel capsules and is contained within the instrument in another stainless steel housing shielded with lead. The interaction between the Americium 241 and the beryllium metal "target" within the sealed capsule results in the emission of approximately 70,000 neutrons per second.

The two sources contained in moisture/density gauges, when unshielded, emit dose rates as follows:

Isotope	Maximum Amount		Dose-Rate (@ 1 meter)
Cs 137	10 millicuries		3.3 mrem/hr
Am 241/Be	50 millicuries		0.11 mrem/hr
		TOTAL	3.41 mrem/hr (with sources exposed)

When the source rod is in the safe position, the Cs137 source is heavily shielded by lead and tungsten carbide and the whole body dose rate at a distance of one meter from the gauge is reduced to 0.5 mrem/hr. The majority of exposure will occur to the users ankles while carrying the gauge to and from the test location. With the gauge hanging down at arms length, the dose rate to the whole body is approximately 0.5 mrem/hr. Therefore, by taking reasonable precautions, no gauge user can receive a radiation dose which exceeds the NRC exposure guidelines. An operator could place his/her hands on the surface of a gauge for 90 hours per week before reaching the maximum recommended radiation dosage for the hand. Assuming a distance of 0.4 meters (16 inches) from the gauge during actual operation, the operator could use the instrument for 300 hours each week without exceeding maximum recommended levels.

Under average conditions, a full time gauge operator working a 40 hour week can expect to receive approximately 4 mrem per week which is only 4% of the maximum permissible dose for an occupational worker. NRC regulations require that any occupationally exposed worker who may receive a radiation dose greater than 10% of the maximum permissible exposure be monitored for radiation exposure.

All authorized Terracon nuclear density/moisture gauge operators will be monitored for radiation exposure by a film badge or TLD device. The employee will be responsible for maintaining the badge in an appropriate manner, and for turning the badge in for analysis on a monthly or quarterly basis. Every Terracon employee monitored for radiation exposure will be provided the opportunity to review the results of exposure monitoring at any time upon request. Results of individual radiation monitoring will be provided each employee on a periodic basis.

C. THEORY OF DENSITY/MOISTURE MEASUREMENT

1. Density and Soil Compaction

In order to adequately support a building, the natural curves, hills and valleys of the earth's surface must be smoothed into flat surface. In order to increase the capability of soils to support man-made structures, the soils are compacted by heavy rolling equipment. Because the depth of compaction efforts is limited by the size and weight of the rolling equipment and the pressure

they can be applied to the soil. In order to maximize the compaction of soils, it is therefore necessary to compact soils in lifts. Borrowed soils are placed on the area to be compacted in 6" to 12" "lifts." Each lift is then compacted before additional fill is placed. As a general rule, clay soils are harder to compact than sandy soils. Measurement of the **density** of compacted soils provides a general indicator of the support which will be provided by the soils.

$$\text{Density} = \frac{\text{mass (kg or lbs)}}{\text{volume } (m^3 \text{ or } ft^3)}$$

The maximum density to which a material, such as soils can be compacted is dependent upon three primary factors:

1) the soil type (i.e., high clay content vs. sandy silt)
2) the moisture content (i.e., the percentage of water contained in the material), and
3) the amount of pressure applied during compaction.

For every type of soil, there is an optimum moisture content which will permit maximum compression. If too little or too much water is present, maximum compaction cannot be achieved.

One laboratory procedure for determining optimal moisture content and maximum theoretical compaction of soils is known as the **Proctor.** This 1930's-vintage test method is described in the American Society of Testing Materials (ASTM) D698. The procedure consists of placing a soil sample of known moisture content in a 6" diameter cylinder and pounding it 56 times with a 2 kilogram (kg) weight dropped from a height of 12". After compaction of three lifts in this manner, the compacted sample is cut to a height of 4.584" and weighed. The density of the resulting compacted material is calculated by comparing the resulting weight (mass) to the known volume. The procedure is then repeated at differing moisture contents until the optimum moisture content to achieve maximum compaction of the soils is determined. ASTM 698 variations have been drafted as heavier compaction equipment has become available.

Due to the time and expense required to compact soils to 100% maximum density, the design specifications for foundations is typically reduced to a percent compaction consistent with and appropriate for the intended use of the compacted area. In preparing foundations for structures such as airport runways, 100% maximum compaction may be specified due to the added support, safety and longevity required. Foundations prepared to support structures will typically specify 95% maximum compaction, while utility trench backfill specifications may be reduced to 90% of maximum compaction.

Maximum density determinations are also made for asphalt applications. As with soils, there exists an optimum "moisture" content to for achieving maximum density, however, in asphalt mixes the liquid is bitumen instead of water and the maximum compaction is primarily dependent on the aggregate selected for the mix design. Laboratory tests similar to the soil Proctor have been developed for determining the maximum density of asphalt mixes, some of which are based on the mix design (Marshall) while others are based on the specific gravity of the aggregate used in the mix (Rice). Typical maximum compaction specs for asphalt applications are 92% based on the Marshall or 95% based on the Rice.

The nuclear density/moisture gauge is one device which has been developed to measure the density of soils and asphalts and to determine the efficiency of compaction efforts. Other methods developed to measure density in construction materials include:

The Sand Cone
The sand cone is a method used in determining the density of soils. A hole is dug in the compacted area and the removed soils are weighed. The hole is then filled with sand of a known specific gravity to determine the volume of the hole. The resulting mass divided by the volume yields the density of the soil. Moisture content is then determined in a laboratory by weighing a sample of the soils before and after oven drying. Sand cones are a relatively accurate test for determining soil density, although they are labor-intensive and time consuming with only four to six tests possible per technician per work day.

The Balloon Test
The balloon test is similar to the sand cone. Like the sand cone, a hole is dug and the soil is removed from the hole and weighed. But, instead of filling the hole with sand to determine volume, a thin membrane or "balloon" is used to line the hole which is then filled with water or oil to make the volume determination.

The Drive Tube
In this test, a rigid tube is driven into the soil, removed, trimmed to a specific height and weighed to determine density. Errors in this test result in tight clay soils and in loose sandy soils. Clay soils tend to compact when the tube is driven which tends to overestimate density while loose , sandy soils tend to fall out of the tube during extraction, making density determination impossible by this method.

Core
In asphalt pavements, density can be determined by coring a sample from the compacted surface and weighing it to determine mass. Volume is determined by floating the core sample in water and measuring the resulting displacement.

2. Gamma Radiation Density Measurement

The Cesium 137 (Cs137) source contained in nuclear density/moisture gauges is a gamma ray source. If a source of gamma energy is placed on one side of a slab of matter (i.e., soil or asphalt) and a gamma ray detector is placed on the opposite side, the intensity of the gamma rays detected will depend on a mathematical relationship between the intensity of the gamma ray source, the thickness and the density of the matter. If the thickness of the material is held constant, the following formula can be used to calculate the density of the material.

$$I = I_o e^{-ut}$$

Where: I = the intensity of gamma rays reaching the detector
I_o = the intensity of the initial gamma ray source
u = the density of the material
t = the thickness of the material

Unfortunately, in addition to being absorbed the material, many gamma rays will be scattered within the material. This is known as the "**Compton Effect**" and can have a significant impact on the gamma rays which reach the detector and can skew the results of the measurement. It is also important to know that the attenuation of gamma rays is not constant over the total range of density. The rate of attenuation of gamma rays is low in low density materials and increases with denser materials. These factors, as well as the composition of the materials under test will affect the readings derived by nuclear density/moisture gauges. Material composition errors, Compton scatter and non-linear attenuation with increasing density must be accounted for by proper calibration of nuclear density/moisture gauges.

3. Nuclear Gauge Direct Transmission Test Method

There are two methods for determining the density of construction materials with a nuclear density/moisture gauge. The first is the **Direct Transmission** method. In the direct transmission method, a pilot hole is made in compacted soils and the retractable source rod containing the Cesium 137 gamma ray source is lowered to a specific depth below ground surface. The gamma ray detector is contained in body of the nuclear density gauge which is positioned on a level spot on the ground surface. The number of gamma rays which reach the detector will be a function of the density of the compacted soil, i.e., loosely compacted soils will permit more gamma rays to reach the detector than tightly compacted soils. Since all of the gamma rays arriving at the detector will have passed through the full distance from the source depth, the measured density is a true average for the material between the surface and the source. The gamma ray detector is connected to electronic circuitry which can display the electronic counts reaching the detector in unit time, or calculate and display a direct reading of the density of the material.

4. Nuclear Gauge Backscatter Test Method

In the backscatter test method, both the gamma ray source and detector are both located at the surface of the material being tested. This method will only measure the top 2 to 3" of the material and is typically used to determine the density of asphalt pavements. The backscatter test method is greatly affected by surface irregularities. Shielding present in the gauge limits bombardment of the gamma ray detector by gamma radiation which has not passed through the material under test.

Since all of the gamma rays which have passed through the material under test have been scattered at least once, the average energy at the detectors is lower than the average energy under direct transmission conditions. For this reason, the error due to chemical composition is significantly larger.

5. Neutron Source Moisture Measurement

The Americium 241/Beryllium source located in the base of nuclear density/moisture gauges used by Terracon is a neutron source. This source is used to determine the moisture content in soils. As you will recall from previous sections, neutrons are uncharged particles emitted from the nucleus of unstable isotopes. The nature of neutrons permits them to penetrate large distances. Because they are neutral, they can penetrate through the outer electron "cloud" of atoms and, in essence, strike the nucleus. This is due to the size of the target (nucleus) in

relation to the neutron. Hydrogen atoms are particularly stable atoms and have little tendency to absorb additional neutrons. Because a neutron and a hydrogen atom are of more or less equal mass, when a neutron strikes a hydrogen atom it will bounce off much like two billiard balls of equal weight striking each other. Neutrons are therefore most effectively slowed when they bounce off of light nuclei such as hydrogen atoms. In bouncing off an atom of similar mass, the neutron will be reflected and will lose a small portion of it's energy. As the neutron strikes additional hydrogen atoms, it loses progressively more energy and slows the neutron. Because more than 97% of the earth's crust is composed of heavier elements such as oxygen, silicon, aluminum, iron, etc., slowing of neutrons passed through soils will be predominantly due to encounters with hydrogen atoms contained in water molecules within the soil.

The neutron detector in nuclear density/moisture gauge is located on the base of the gauge in relatively close proximity to the Am 241:Be source. The detector is "blind" to the fast neutrons emitted by the Am 241:Be source, and is designed to detect only slow, or **thermal** neutrons which have been bounced back from hydrogen atoms in the soil. The thermal neutron detector in the nuclear density/moisture gauge counts the thermal neutrons and electronics connected to the detector calculate the approximate moisture (water) content of the soils.

D. CALIBRATION

1. Factory Calibration

All density/moisture gauges require periodic calibration for the various source rod positions and the "backscatter" position. At least three data points are required for proper calibration and calibration is therefore typically performed on three standards representing low, moderate and high density. This calibration is typically conducted at the factory and will be included with the instrument as a set of curves, a set of tables or will be programmed into the electronics of microprocessor containing devices.

2. Use of the Reference Standard

In previous sections of this manual, the concept of half-life was discussed. As you will recall, the half-life is the time it takes for half of the radioactive atoms in a radioisotope to decay. The Cs 137 gamma source in nuclear density/moisture gauges has a half life of 30 years, while the Am241 neutron source has a half-life of approximately 458 years. Because of the decay which is continually occurring within the sources, periodic correction must me made to account for the decay.

The density (Cs 137) channel must be corrected approximately every two weeks Correction of the density radiation source channel Is performed using the **reference standard** supplied with the instrument.

The reference standard is a large block of plastic material with a known density and hydrogen content. To calibrate the density and moisture channels using the reference standard block, the block must first be placed on a dry, flat surface at least six feet away from buildings or other large structures and at least thirty feet from any other radioactive source. The surface for the calibration check can be asphalt or concrete paving, compacted aggregate or similar surface

provided the moisture content is less than 240 kg/m^3 (15 PCF) moisture. Truck beds, tables or tailgates can NOT be used to conduct reference standard calibration.

Place the instrument on the reference standard block as indicated in the operators manual supplied with the gauge. You must ensure that the top of the reference standard and the base of the gauge are clean and free of soil or other material which will prevent good surface contact. Carefully read the operators manual to ensure proper positioning of the gauge on the reference standard block.

Calibration of the density and moisture channels are made in terms of a ratio to a count made on the reference standard. For this reason, measurements made with the instrument can be no more accurate than the accuracy of the standard counts. The accuracy of the instrument is therefore dependent on the care taken in establishing reference standard counts. A log should be kept of these 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 in either the calibration procedure or the instrument.

In general, a sudden shift of more than 1 percent in the density standard count or 2 percent in the moisture standard count, as compared to the average of the previous four sets is an indication of an abnormality in gauge operation or procedure. A hands-on demonstration of the reference standard calibration for each type of density gauge you may be assigned to use will be conducted as part of this training and orientation program. It is important that each Terracon gauge operator understand that Terracon owns and operates nuclear density/moisture gauges from both leading manufacturers, Troxler Electronic Laboratories (Troxler) and Campbell Pacific Nuclear (CPN). Calibration procedures between manufacturers and between different gauge models will vary. The instructions contained in the operators manual for each specific gauge must be followed in reference standard calibrations.

E. COMMON ERRORS IN NUCLEAR DENSITY/MOISTURE MEASUREMENT

Errors in nuclear density/moisture measurements can occur due to a number of factors including operator error, calibration error, electronic failures within the gauge and aberrant soil conditions. Soils are heavier than water. Water has a density of approximately 62.5 lbs/ft^3 while un-complicated soils will have a density closer to 70 lbs/ft^3. Soil density readings below 70 lbs/ft^3 should be considered suspect while density readings below the 62.5 lbs/ft^3 will be in obvious error. Likewise, the density of granite is approximately 165 lbs/ft^3. Soil density readings of this magnitude will also most certainly be in error.

Examples of other errors which can occur in nuclear density/moisture measurements can include the following:

1. Circuitry Malfunction

Circuitry errors can include failure of the detectors, electronic components or a low battery. These errors typically occur suddenly although they may be intermittent or gradual in nature.

2. Operator Errors

Some common operator errors include:

Improper calibration (i.e., selecting the wrong calibration curve for the wrong gauge). Failure to lock the source rod in the positive detent position can also have a significant impact on the test result. The source rod in each gauge contains positive detents or notches which are calibrated for various source rod depths. Having the source rod out of the detent position by as little as 0.005" can result in a density error of as much as 0.025 lb/ft^3 at 6".

Another common operator error is failure to position the source rod against the side of the test hole. Once the test hole has been created, the entire gauge must be pushed so that the source rod is up against the side of the hole. This measure eliminates the air gap through which the gamma rays would be forced to travel. Failure to position the source rod against the test hole can reduce the density measurement by as much as 0.5 lb/ft^3. Improper seating of the gauge base

Improper seating of the base of the gauge can result in low density measurements, especially when the source rod is in the backscatter position. The scraper plate must be used to smooth off and level out the test site. Sliding the gauge back and forth prior to running the test will help further ensure proper seating of the base. An air gap of 1/4" can cause a 6" depth transmission mode density reading to read light by as much as 1 lb/ft^3.

3. Application Errors

Wet Surfaces
The density reading for materials which have been recently wetted will measure higher than the true wet density due to water retained in the pores of the soil, and because of the greater sensitivity of the readings near the surface.

Proximity to Objects
Factory calibration of gauges is conducted on a flat, open surface. Proximity to structures such as buildings, trench walls, etc. will cause reflected energy, especially neutrons, to reach the detector resulting in increased counts.

Non-Soil Material in Measurement Path
When taking density readings in transmission mode, buried boulders or debris which block the path of gamma rays back to the detector in the gauge can result in elevated density readings. Conversely, large subsurface air voids can result in low density readings. The gauge must be rotated whenever and the readings repeated whenever these conditions are suspected.

F. NUCLEAR MATERIALS LICENSING AND REGULATORY REQUIREMENTS

Nuclear density/moisture gauges and the sealed radioactive sources contained within them have been designed with operator and public safety as a primary consideration. One device manufacturer has stated that in over twenty years of manufacturing nuclear density gauges, no radioactive source has ever shown a positive leak test, despite involvement of the gauges in fires or accidents.

However, it is important for each authorized gauge operator to know that the radioactive material contained in each nuclear density/moisture gauge represents a hazard to the gauge operator and the general public if it is not used properly. In order to protect the operator and the general public, federal and state governments have developed licensing requirements and regulations which govern the possession and use of these devices.

The primary regulatory enforcement agency in the United States is the Nuclear Regulatory Commission, or **NRC**. NRC regulations permit states to operate their own nuclear regulatory programs for certain licensed radioactive materials, including nuclear density/moisture gauges, provided the regulations are at least as stringent as those developed by the federal authority. As of 1996, 29 states were administering their own radiation safety programs under agreement with the Federal NRC. These states are typically referred to as **Agreement States**. . Federal NRC radiation safety regulations govern in the remaining 21 "**NRC states**."

In order to possess nuclear density/moisture gauges in an NRC or an agreement state, a **radioactive materials license** is required. To obtain a license, the licensee must designate an individual who has primary responsibility for ensuring that the material is used in accordance with governing regulations and license conditions. This individual is referred to as the Radiation Safety Officer or Radiation Protection Officer. Subordinate Radiation Safety Officers are designated at each location where licensed materials will be permanently stored.

NRC and agreement state licenses contain various conditions and requirements the licensee must follow to protect operators and the general public from potential harm. Although some variations exist between NRC and agreement state license conditions, the following is an outline of common major requirements.

"ALARA"
Each licensee is required to maintain a written radiation safety program designed to maintain radiation exposure of gauge operators and members of the general public "As Low As Reasonably Achievable" (ALARA). Work practices, prohibitions against other than minor maintenance of gauges, storage practices, etc. must be established which will minimize potential radiation exposures.

Training
Every employee permitted to operate a nuclear density/moisture gauge must be receive training in a course which has been approved by the NRC or state radiation regulatory agency. These courses are typically conducted by the manufacturer, but may be conducted by the employer or an outside agency with appropriate approval. The licensee is required to maintain certificates of operator training for inspection by the radiation authorities. Periodic re-training is required by some agreement states.

Transportation
Nuclear density moisture gauges are considered hazardous materials by the Department of Transportation. Their shipment by private or common carrier is therefore subject to DOT hazardous materials shipping requirements. These requirements include provisions for proper packaging, marking, labeling and documentation. The devices must also be secured at all times during transportation. Additional information on DOT hazardous materials transportation requirements are contained in later sections of this presentation.

Security
Licensees are required to ensure that nuclear density/moisture gauges are secured against theft, damage or loss. A sign-in/sign-out procedure is required to account for their whereabouts at all times. When not actually in use, the devices must be locked in their shipping containers and locked within a storage closet or other secure enclosure. Personnel using gauges in the field are required to maintain sight of the gauges at all times and to secure them within the shipping container and secure the container against theft when the gauges are not actually in use.

Documentation
License conditions require the authorized operators to maintain a copy of the radioactive materials license and a copy of the most recent leak test in their possession at all times. Written emergency procedures, proper shipping papers and a gauge operators manual are also required by DOT regulations and/or agreement state requirements. A package of required documents should be maintained in the shipping case of each gauge, and must be periodically updated when licenses are amended and when new leak tests are performed.

Radiation Monitoring
As discussed earlier in this presentation, radiation exposure monitoring of all authorized users of licensed materials is required by the NRC and agreement states whenever radiation exposures exceed 10% of the maximum permissible dose limits. Some agreement states permit nuclear density/moisture gauge licensees to discontinue radiation monitoring if sufficient data has been accumulated to demonstrate that radiation exposures do not exceed minimal limits.

Leak Tests and Inventory
Licensing authorities require that the sealed sources on every nuclear density/moisture gauge be tested for leakage at a specified period, typically every six months. Records of leak tests and a periodic inventory of all devices possessed under the radioactive materials license must be maintained for inspection by the governing radiation regulatory agency.

Written Accident Procedures
Procedures outlining the steps an authorized gauge user must take in the event that a licensed device is damaged must be developed and must be in the possession of the operator at all times. This procedure must contain the emergency telephone numbers of the radiation safety officer and the governing radiation regulatory authorities.

G. TERRACON RADIATION SAFETY PLAN

1. Purpose

This radiation safety plan defines procedures for the safe handling and use of radioactive materials contained in portable moisture/density and asphalt content gauges. The provisions contained in this plan are designed to ensure that radiation exposure to Terracon personnel and members of the general public are maintained as low as reasonably achievable (ALARA). When handled and stored in accordance with this plan, and used for their intended purpose in accordance with the manufacturer's instructions, the sealed sources contained in the gauges pose a minimal hazard to employees, clients or the general public.

2. Responsibility for Radiation Safety

a. Corporate Radiation Safety Officer (RSO)

All use and possession of nuclear source gauges is under the direction and supervision of the Terracon Corporate Radiation Safety Officer and the local Deputy Radiation Safety Officer. The Corporate RSO is responsible for all aspects of this radiation safety plan and is directly accountable to the President and CEO of The Terracon Companies, Inc. The duties and responsibilities of the Corporate RSO are as follows:

1. To maintain and ensure compliance with Terracon State and Federal NRC licenses.
2. To issue notices for timely leak testing of all nuclear gauges.
3. To ensure that nuclear source operators are trained and enrolled in Terracon Corporate radiation monitoring program. Operators in the States of Colorado and Texas shall wear dosimeters capable of detecting alpha, beta, gamma and neutron radiation.
4. To ensure maintenance of records required by the terms and conditions of State and Federal NRC licenses.
5. To establish policies requiring nuclear gauge security.
6. To assist in the event of an emergency such as field equipment damage, theft or fire and to notify the appropriate licensing authority.
7. To ensure that operators read, understand and adhere to this radiation safety plan.
8. To distribute mandatory signs and postings to all offices.
9. To communicate regulatory requirements and pertinent information to Deputy Radiation Safety Officers.
10. To arrange for radiation surveys of office spaces or incident sites as may be required by the NRC or State.

b. Deputy Radiation Safety Officer

1. To ensure that nuclear source gauges are used only by trained and authorized users wearing appropriate radiation monitoring devices.

2. To ensure that radiation monitoring devices (film badges supplied by Landauer, Inc.) are issued and returned for analysis monthly; and to ensure that monthly reports are posted in a prominent location or distributed to each authorized user.

3. To conduct bi-annual inventory of all licensed devices and to ensure bi-annual leak testing of all nuclear source gauges. Inventory and leak testing will be conducted simultaneously on the first of January and July of each calendar year.

4. To maintain local office records as required by State and Federal NRC licenses.

5. To ensure that all mandatory information and postings are prominently displayed. (See Posting Requirements below.)

6. To forward leak test, training certificates and other mandatory records to Corporate RSO

7. To notify Corporate RSO in event of nuclear source gauge theft, loss or damage.

8. To ensure that all nuclear source gauges are secured against theft or unauthorized removal.

c. Authorized User Responsibilities

1. **Authorized users of sealed source nuclear gauges will exercise control over nuclear gauges at all times. At no time will gauge be left unattended or in the possession of unauthorized personnel.**

2. Each authorized operator will sign gauges out each time they are removed from their permanent storage location. Sign-in/sign-out sheets shall remain on Terracon premises. Sign-out log sheet will include the manufacturer, model and serial number of the gauge, the date and name of the authorized user removing the gauge, the proposed location of use and the date on which the gauge was returned to storage.

3. Gauges will be signed in and returned to the permanent storage location as soon as possible upon completion of field testing.

4. When not in use, gauge source rods will be returned to the locked "safe" position; each gauge will then be <u>locked</u> in the proper storage/transportation case utilizing a key operated padlock.

5. The operator will not use any nuclear source gauge unless the individually assigned radiation monitoring device is worn. The monitoring device will be maintained in a radiation free, room temperature environment when not in use.

6. Each authorized user will use nuclear source gauges only for their intended purpose in accordance with the manufacturer's instructions. Efforts shall be made to ensure that radiation exposure remains "As Low As Reasonably Achievable" (ALARA), i.e., by carrying gauges with source rod in the locked "safe" position.

7. Before removing gauge from Terracon premises, the operator shall ensure that the following documents are contained in the shipping case:

   a. Copy of current license.
   b. Copy of this radiation safety plan.
   c. Copy of manufacturer's instruction/user manual.
   d. Copy of most current leak test certificate.
   e. A properly completed DOT Shipping Paper (Appendix 1).

3. Receipt of Sealed Source Nuclear Gauges

Prior to receipt of sealed source nuclear gauges, the Local RSO will ensure that:

a. The appropriate State or NRC Notice to Employees for Radiation Protection is posted in a prominent location in the facility.

b. Post a current copy of the nuclear materials license or a notice describing the license and indicating where it and governing Radiation Control Regulations may be examined.

c. A copy of the appropriate State or Federal Radiation Control Regulations will be obtained.

d. Establish a secured storage area marked with Caution: Radioactive Material signs.

e. Ensure that a current leak test certificate accompanies the sealed source gauge. If the leak test certificate is greater than 6 months old, a leak test will be performed and results obtained before the gauge is used.

f. When new gauges are received, inspect the shipping container prior to opening. If shipping containers are damaged or show evidence that the unit has been dropped, run over, etc. DO NOT OPEN the case. Immediately contact the Corporate RSO to arrange for radiation survey and to receive storage instructions.

4. Transportation

a. Nuclear source gauges will only be transported in DOT approved shipping containers.

b. Authorized users will complete hazardous materials transportation training courses in accordance with DOT and Department regulations prior to transporting nuclear density/moisture gauges.

c. During transportation, all gauges will be fully secured to the vehicle and located as far from personnel as possible. Shipping cases will be locked and securely fastened with a key-operated padlock. The shipping case will be securely locked to a structural component of

the vehicle using a chain of suitable strength and a key-operated padlock. Gauges will also be secured in accordance with the above whenever they are away from the permanent storage site and not actually in use.

d. DOT regulations require that a properly completed DOT Shipping Paper be **within reach** of the driver at all times during transportation.

e. DOT approved shipping containers will be properly marked and labeled. Each gauge case will bear "Radiation II" labels on two opposing sides. Each Radiation II label will have the "Contents," "Activity," and "Transport Index" sections properly completed. The top side of each case shall also bear a "Cargo Aircraft Only" label and the following package marking in close proximity:

USA DOT 7A
TYPE "A"
R.Q., RADIOACTIVE MATERIAL, SPECIAL FORM, N.O.S.
UN 2974

f. Package markings and labels will be inspected on a quarterly basis and will be replaced whenever they become torn or obscured. The Deputy RSO will maintain a record of quarterly labeling inspections and will note dates on which labels are replaced. These records will be made available for inspection by the appropriate state or federal licensing agency.

5. <u>Leak Testing/Maintenance</u>

a. Leak tests will be performed on all sealed source nuclear gauges at bi-annual intervals as specified in the applicable State or federal NRC license. Leak tests will utilize Model 86 test kits supplied by Pacific Nuclear Technology Co., 2545 West 10th Street, Antioch, CA 94509. Leak tests will be performed in accordance with device manufacturer's instructions.

b. No Terracon employee will perform any maintenance involving removal of sealed radiation sources from the gauge. With the exception of 3. and 4. below, all maintenance will be performed by the gauge manufacturer or an appropriately licensed entity specifically approved by the gauge manufacturer.

c. Gauges will be inspected and the shutter mechanism will be cleaned and lubricated on a monthly basis in accordance with the manufacturer's instructions. Individuals servicing shutter mechanisms will wear radiation monitoring badges at all times. The handle assembly will be inspected for wear in accordance with the following:

1. Set handle to the "BS" position.

2. Loosen Allen screw on side of guide tube ONLY until handle is free. DO NOT REMOVE SCREW.

3. Pull handle away from guide tube.

4. Check beveled front edge of handle latch for excessive wear and check notches inside guide tube for excessive wear.

5. If wear on the notches or latch appears excessive, ship unit to the manufacturer immediately for repair. Terracon personnel will not attempt to perform repairs.

d. Shutter mechanism will be cleaned and lubricated monthly or whenever the source rod begins to stick upon retraction. Procedure for shutter cleaning shall be as follows:

1. Lie gauge on an end or side ensuring that the base is pointing toward a solid exterior wall AWAY from personnel.

2. Stand behind gauge and remove the screws securing the shutter assembly.

3. Remove shutter assembly. DO NOT touch the source rod tip or stand in front of the base of the unit after shutter block is removed.

4. Standing BEHIND the gauge, clean exposed area at base of gauge with long handled brush or compressed air. DO NOT touch source rod tip.

5. Clean shutter assembly and spray with lubricant recommended by manufacturer.

6. Re-install shutter block assembly from BEHIND GAUGE. Ensure rod moves freely.

6. **Training**

a. All authorized users will complete a radiation safety training course provided by either Troxler Electronic Laboratories, Campbell-Pacific Nuclear or other training source approved by the governing regulatory agency. No Terracon employee may possess or operate a sealed source nuclear gauge until trained and authorized by the Local RSO.

b. Terracon will attempt to hire only those individuals who have received radiation safety training and who have had previous experience in nuclear densometry.

c. Deputy RSO's are responsible for ensuring that all new hire and temporary personnel receive mandated training courses prior to allowing operation of gauges. Deputy RSO's will inform the Corporate RSO of personnel changes as they occur.

d. The Deputy RSO will demonstrate the use of Terracon gauges to all new hire personnel. The Deputy RSO will accompany new hire personnel to job sites for the first two weeks of employment or until proficiency has been demonstrated. The Deputy RSO will then perform periodic inspections of job sites to ensure that authorized users comply with Terracon procedures and applicable provisions of the nuclear materials license.

7. **Records Maintenance**

a. With the exception of daily utilization logs, the Corporate RSO will maintain all records required by State and federal NRC license requirements. The Deputy RSO will maintain

copies of ALL records required by applicable NRC or State license conditions.

Records which will be maintained in the Corporate Office and in each office where gauges are used or stored will include:

- Personnel radiation exposure reports
- Leak tests
- Training certificates
- Sealed-source nuclear gauge inventory
- Utilization Logs
- Inspection Records

b. The Deputy RSO will post or distribute all monthly radiation dosimetry reports. No affected Terracon employee shall be denied the right to view and copy radiation dosimetry reports.

8. **Posting Requirements**

a. The Deputy RSO at each Terracon facility will ensure that NRC or State "Notice to Employees" and a copy of the Terracon Emergency Action Plan are prominently posted in areas frequently accessed by authorized users.

b. An additional notice to employees informing them where the NRC or State license and NRC or State radiation regulations may be viewed will also be posted.

c. Storage areas will be properly posted with the international radiation symbol and the words: CAUTION RADIOACTIVE MATERIALS. Labels may be obtained from the Corporate RSO.

d. Required postings will be inspected on a monthly basis. The Deputy RSO will replace missing or defaced postings required by this section.

9. **Disposal**

a. Disposal of all sealed source nuclear gauges will be the responsibility of the Corporate RSO.

b. Disposal will be performed by transferring to a properly licensed organization or disposal facility.

10. **Emergency Procedures**

a. Theft or Loss

Implement procedures contained in attached Emergency Action Plan. When the situation has stabilized sufficiently, notify the Deputy and Corporate RSO. Deputy or Corporate RSO will immediately telephone the appropriate radiation licensing authority of the loss or theft. Local law enforcement officials will also be notified and a police report will be obtained. After discussion with the President, The Terracon Companies, Inc., a press

release describing the device, circumstances and location of loss and contact number will be prepared and issued. The Deputy RSO will notify the gauge manufacturer and other laboratories in the area alerting them to the model and serial number of the missing gauge. The Corporate RSO will ensure that any written reports or summaries which may be required by radiation control regulations are submitted within the specified time period.

b. Failed Leak Test

1. If leak test result from any nuclear gauge reveals removable contamination exceeding **0.005 microcuries**, immediately notify the Corporate Radiation Safety Officer.

2. The gauge will be immediately removed from service and locked in its DOT approved shipping container. The container and contents will be locked in the storage area.

3. The Corporate RSO will arrange for a radiation survey by contacting the local device manufacturer's office (if available) or local safety equipment rental office. A radiation survey instrument capable of detecting alpha, beta, gamma and x-ray radiation will be utilized and results will be promptly reported to affected personnel and the local radiation authority.

4. The Corporate RSO will contact the manufacturer of the leaking gauges and will notify affected office of additional steps to take after consultation with the manufacturer.

c. Lost or Damaged Radiation Monitoring Badge

1. Lost or damaged radiation monitoring badges will be immediately reported to the Local RSO. Individuals without radiation monitoring badges will not be permitted to operate sealed source gauges until a replacement monitoring badge is obtained.

2. The Local RSO will notify the Corporate RSO of the lost or damaged monitoring badge. The Corporate RSO will notify Landauer, Inc. of the loss and request a replacement.

3. Utilization logs and average of previous monthly monitoring reports will be used to estimate dosage received during the monitoring period. The estimate will be forwarded in writing to the film badge service provider with a request that the estimated exposure be included on the individual's exposure history.

11. Radiation Safety Program Review

The Corporate RSO will contact the Local RSO's on an annual basis and request a review of the Radiation Safety Program. Storage and transportation procedures, utilization logs, posting, authorized user training and recordkeeping requirements will be reviewed during the annual program evaluation.

H. HAZARDOUS MATERIALS TRANSPORTATION

1. Introduction

Highway shipments of hazardous materials are governed by U.S. Department of Transportation Hazardous Materials Regulations found at 49 CFR, Parts 100-177. Terracon personnel will abide by the applicable regulations when packing, marking, labeling and documenting highway shipments of hazardous materials.

2. Definitions

Hazardous Material
Means a substance or material, including a hazardous substance, which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety and property when transported in commerce, and which has been so designated, i.e, any chemical or material listed by name in the DOT Hazardous Materials Table, Part 172.101.)

Hazardous Substance
A material which has been assigned an "RQ" (Reportable Quantity) value by the U.S. EPA under CERCLA Section 101(14), and which is being shipped in a (*per package*) quantity that exceeds the RQ. All Yellow II radioactive materials are considered hazardous substances.

Proper Shipping Name
Means the name of the hazardous material shown in the DOT Hazardous Materials Table in 49 CFR Section, 172.101. Text appearing in italics are for clarification only and are NOT a part of the proper shipping name.

UN Number
A unique identification number assigned to each hazardous material by the United Nations Committee of Experts on the Transport of Dangerous Goods, an international UN working group. Some materials bear an NA number. These materials have not been evaluated by the UN working group and may only be transported in North America.

Marking
Information which must be durably and legibly marked on the outside of all hazardous materials shipments. Package markings include: 1) Name and address of Shipper or Consignee, 2) Proper Shipping Name, 3) UN Number

Labeling
All shipments of hazardous materials will be labeled in accordance with Part 173 of the DOT Hazardous Materials Regulations.

Hazard Class
Hazardous materials are assigned to specific classes under criteria established in Section 173 of the DOT Hazardous Materials Regulations. Certain hazard classes, such as gases (Class 2), are sub-divided into Divisions. A material may meet the definition of more than one hazard class but is only assigned one hazard class based on a precedence of hazards hierarchy. The DOT hazard class/divisions and the materials they represent are presented in the table below.

Hazardous Material Category		Hazard Class/Division
Explosives (Mass Explosion Hazard)	--	1.1
Explosives (Projection Hazard)	--	1.2
Explosives (Predominantly Fire Hazard)	--	1.3
Explosives (No Significant Blast Hazard)	--	1.4
Very Insensitive Explosives (Blasting Agents)	--	1.5
Extremely Insensitive Detonating Substances	--	1.6
Flammable Gas	--	2.1
Non-Flammable Gas	--	2.2
Poisonous Gas	--	2.3
Flammable Liquids	--	3
Flammable Solid	--	4.1
Spontaneously Combustible Material	--	4.2
Dangerous When Wet	--	4.3
Oxidizer	--	5.1
Organic Peroxide	--	5.2
Poisonous Materials	--	6.1
Infectious Substances (Etiologic Agents)	--	6.2
Radioactive Material	--	7
Corrosive Material	--	8
Miscellaneous Hazardous Material	--	9

U.S. DOT Precedence of Hazards Table

Class/Division		Specific Definition
7	--	Radioactive Materials
2.3	--	Poison Gases
2.1	--	Flammable Gases
2.2	--	Non-Flammable Gases
6.1, PG I	--	Poisonous Liquids (Poisonous by Inhalation)
4.2	--	Spontaneously Combustible Material (Pyrophoric)
4.1	--	Flammable Solid (Self-Reactive)
3	--	Flammable Liquid
8	--	Corrosive Materials
4.1	--	Flammable Solid (*Non* Self-Reactive)
4.2	--	Spontaneously Combustible Material (*Non*-Pyrophoric)
4.3	--	Dangerous When Wet
5.1	--	Oxidizers
6.1, *NOT* PG I	--	Poisonous Materials (Other Than Poisonous by Inhalation)
9	--	Miscellaneous

Packaging

Means a receptacle and any other components or materials necessary for the receptacle to perform its containment function in conformance with the minimum packing requirements as specified in the DOT Hazardous Materials Transportation Regulations.

Specification Packaging
Means a packaging (i.e., drum, fiberboard box, cylinder, etc.) conforming to one of the DOT specifications or standards for hazardous materials packagings. The US DOT specifies that nuclear materials be carried in one of two classes of packagings--Type A and Type B. Type B packagings are for containment of high level radioactive materials while Type A packagings are for lower level materials. All nuclear density/moisture devices are transported in Type A packagings. A package must be certified as a TYPE A package by a "competent authority" certificate issued by the DOT.

Hazardous Materials Shipping Paper
All highway shipments of hazardous materials must be documented through use of a shipping paper containing the information required by DOT Hazardous Materials Regulations, Part 172, Subpart C.

3. Preparation of Hazardous Materials for Highway Shipment

Proper preparation of hazardous materials shipments involves each of the following steps:

A) Classification
B) Packaging Selection
C) Packing
D) Marking
E) Labeling
F) Preparation of Hazardous Materials Shipping Paper

A. Classification -- (Selection of Proper Shipping Name)

<u>R.Q., RADIOACTIVE MATERIAL, SPECIAL FCRM, N.O.S.</u>

This is the proper shipping name assigned to any number of low level radioactive instruments and articles including nuclear density/moisture gauges.

B. Packaging Selection

Only Type A packagings specified by DOT competent authority certificate may be used to transport radioactive materials. Use only the manufacturer's shipping container for transporting nuclear density/moisture gauges.

C. Packing

Packing is the physical act of containerizing a hazardous material for transportation. Inspect the shipping container to ensure there is no significant damage that could cause the gauge to be released during transport. Ensure that hinges and closures are in good shape and that the case is LOCKED for transport. Locking the devices is required by both DOT and NRC/State license requirements.

D. Marking

Marking is *NOT* labeling. Required packaging markings for a Type A radioactive materials shipment are as follows:

R.Q., Radioactive Material, Special Form, N.O.S.
UN2974
USA DOT 7A, Type A Package

Use the labels provided by the manufacturer wherever possible. If labels become torn or defaced, it is acceptable to prepare your own marking. It is recommended that the above information be written on a white adhesive label with a black magic marker. The information must be LEGIBLE.

E. Labeling

1. Hazard Labels

The U.S. DOT specifies different hazard warning labels for each category of hazardous material. Unlike most other hazard classes, radioactive materials shipments require TWO hazard warning labels. Nuclear density/moisture gauges require YELLOW II radioactive materials labels--one each on opposing sides of the shipping container. Note that the Yellow II label contains a space for the TI or Transport Index. This is calculated by the manufacturer for each gauge. If labels become worn or defaced, they must be replaced immediately. Be sure to copy over the TI info from the previous label or manufacturer's instruction.

2. Subsidiary Labels

As Yellow II radioactive materials packages are not authorized for shipment on passenger aircraft, DOT requires that all such packages bear a subsidiary Cargo Aircraft Only label. Only one Cargo Aircraft Only label is required. Labels cannot overlap around corners of the package.

4. Hazardous Materials Shipping Paper

Each DOT Hazardous Materials Shipping Paper must include the *name and address of the shipper*, plus the following additional information:

a)Proper Shipping Name
b)Hazard Class/Division Number
c)UN ID Number
d)Packing Group Assignment
e)Number of Packages and Quantity of Hazardous Materials

The BASIC DESCRIPTION, consisting of items 1--4 above must be presented in exact sequence with no other information interspersed. The quantity and type of packaging information may be placed before or after the BASIC DESCRIPTION. If the material being shipped is a HAZARDOUS SUBSTANCE, the basic description must be preceded by the letters "RQ." The final requirements for the DOT shipping paper are:

f) Emergency Response Information including a 24-hour Emergency Telephone Contact
g) Certification statement
h) Signature of preparer

U.S. DOT regulations do not require a specific shipping paper form for *HIGHWAY* shipments of hazardous materials. As long as the required information is present, a DOT Hazardous Materials Shipping Paper could be written in crayon on a used paper bag. (Of course the carrier may have higher standards.)

Unlike highway shipments, *air* shipments of hazardous materials must be documented using a standard Shippers Declaration for Dangerous Goods form developed and required by the International Air Transport Association (IATA).

5. Emergency Response Information

Per 49 CFR 172.600, Emergency response information must be available during transportation and at facilities where hazardous materials are loaded for transportation, stored or otherwise handled incident to transportation. This requirement may be satisfied in a number of ways. Terracon satisfies this requirement by maintaining a copy of our emergency procedures in the facility and with the shipping papers at all times.

The DOT requires that shipping papers (shipping paper AND Emergency Action Procedures) be within reach of the driver at all times during transport. It is recommended that the documents be placed in an envelope clearly marked Nuclear Gauge Shipping Paper. Clip the envelope to the visor of each vehicle that will be used to transport nuclear gauges.

6. Placarding

Placards are the large versions of DOT hazard labels that you see on the side of transport vehicles. DOT regulations do not require vehicles transporting nuclear density moisture gauges to be placarded.

NUCLEAR MATERIALS EMERGENCY ACTION PLAN

THIS EMERGENCY ACTION PLAN APPLIES TO THE FOLLOWING MATERIAL:

NUCLEAR DENSITY/MOISTURE GAUGES AND ASPHALT CONTENT GAUGES

R.Q., RADIOACTIVE MATERIAL, SPECIAL FORM, N.O.S., 7, UN2974

HEALTH HAZARDS

External radiation from unshielded radioactive material.
Internal radiation from inhalation, ingestion or skin absorption of unshielded material.
Runoff from fire control or dilution water may contaminate land/waterways.

EMERGENCY ACTION IN THE EVENT OF DAMAGE TO NUCLEAR GAUGES

1. **Immediately isolate the area and deny unauthorized personnel entry.**
2. **Keep unautho' ' personnel at least 150 feet upwind of damaged gauge.**
3. **Notify Local Radiation Safety Officer and Corporate Radiation Safety Officer at (913) 599-6886 or (913) 649-5234.**
4. **The Local or Corporate Radiation Safety Officer will contact Illinois Dept. of Nuclear Safety at (217) 785-0600.**
5. **Delay cleanup efforts until arrival or instruction of local radiation authority.**
6. **Attempt to detain equipment and uninjured persons until arrival of local radiation authority.**

FIRE

1. **Do not move damaged containers; move undamaged containers out of fire zone.**
2. **Immediately notify fire department, local radiation authority and the Corporate Radiation Safety Officer.**

THE DEPUTY RADIATION SAFETY OFFICER FOR THE ______________ OFFICE IS:

________________________ (708) 540-8080.

U.S. DEPARTMENT OF TRANSPORTATION

HAZARDOUS MATERIALS SHIPPING PAPER

From: Terracon Consultants, Inc.
785 Oakwood Road, Unit E101
Lake Zurich, Illinois 60047

To: Terracon Consultants, Inc.
785 Oakwood Road, Unit E101
Lake Zurich, Illinois 60047

R.Q., RADIOACTIVE MATERIAL, SPECIAL FORM, N.O.S., 7, UN2974
10 mCi Cs-137
50 mCi Am-241:Be
Yellow II
Transport Index: 0.4

USA DOT 7A, Type A Package

See Emergency Action Plan Attached

24-Hour Emergency Contact:

For TROXLER Gauges	(919) 839-2676
For CPN Co. Gauges	(800) 535-5053
Corp. Radiation Safety Officer	(913) 599-6886 or (913) 649-5234

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

____
Local Radiation Safety Officer

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

1. Fast neutrons are best slowed by:
   a) lead
   b) hydrogen
   c) asbestos
   d) air

2. Atoms of the same element having different numbers of neutrons are called:
   a) isotopes
   b) surrogates
   c) gluons
   d) quarks

3. The process by which radioactive isotopes become stable is known as:
   a) distention
   b) radioactive decay
   c) serendipity
   d) synchronous

4. The rate of radioactive decay of a radioactive isotope is usually expressed in terms of its:
   a) atomic number
   b) neutron flux density
   c) half-life
   d) field strength

5. The amount of shielding required to stop one-half of the radiation emitted by a gamma radiation source is referred to as the:
   a) half-value layer
   b) triple point
   c) majority interest
   d) Curie

6. The quantity of ionizing radiation of any type which, when absorbed by man produces a physiological effect equivalent to that produced by the absorption of one Roentgen of X- or gamma rays is the:
   a) Roentgen
   b) Rad
   c) Rem
   d) Calorie

7. Radiation measuring instruments usually provide a measurement of either dose or ____________________.
   a) source material
   b) Curies
   c) magnetic density
   d) dose-rate

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

8. The film badge is a commonly used as a method of measuring the accumulated radiation dose received by an individual. T or F

9. Radiation dose is equal to the dose-rate multiplied by the duration of exposure, or, **Dose = Dose-Rate x Time Exposed**. What is the dose received by an individual exposed to 0.5 millirems/hour, 3 hours per day for a 5 day work week?
   a) 400 millirems
   b) 3 rems/hr
   c) 7.5 millirems
   d) 4 rems

10. The three primary principles employed to protect individuals against radiation are:
   a) education, sodium and water
   b) time, distance and shielding
   c) glass, monitoring and regulation
   d) soil, asphalt and concrete

11. The intensity of radiation at any distance from a radioactive source decreases in accordance with the:
   a) Peter Principle
   b) Compton Effect
   c) Prime Rate
   d) Inverse Square Law

12. The maximum allowable radiation dose limit for adult workers over the age of 18 years is:
   a) 5,000 millirems/year
   b) 10 microcuries/year
   c) 5 rem/year
   d) Both a and c above

13. Nuclear density/moisture gauges contain which of the following radioactive isotopes:
   a) Uranium 238 and Nickel 63
   b) Tellurium 127 and Rubidium 86
   c) Americium 241 and Cesium 137
   d) Strontium 90 and Plutonium 239

14. The sealed Cesium 137 source contained in nuclear density gauges emits what type of radiation:
   a) beta
   b) gamma
   c) alpha
   d) krypton

15. The operator is responsible for nuclear/density moisture gauges at all times while it is in his/her possession. T or F

16. When the Cesium 137 source is in the safe, shielded position, a nuclear density/moisture gauge hanging down at arms length exposes the operator to what dose rate?
   a) 5 rems/hr
   b) 50 millirems/hr
   c) 3 curies/hr
   d) 0.5 millirems/hr

17. Radioactive materials such as nuclear density/moisture gauges are regulated by:
   a) the U.S. Nuclear Regulatory Commission
   b) Agreement States
   c) the U.S. Department of Agriculture
   d) both a and b above

18 The two methods of determining the density of construction materials with a nuclear density/moisture gauge are:
   a) backscatter
   b) seismic
   c) direct transmission
   d) both a and c above

19. A standard count using the reference standard block supplied by the gauge manufacturer must NOT be conducted in a truck bed or on a tailgate. T or F

20. Radioactive materials licenses issued by the U.S. NRC or an Agreement State will typically contain conditions requiring which of the following?
   a) radiation monitoring of gauge users
   b) periodic leak testing and inventory of licensed devices
   c) training of authorized gauge operators
   d) all of the above

21. The Americium 241/Beryllium source in nuclear density/moisture gauges is a neutron source. T or F

22. Leak tests of sealed sources contained in nuclear density/moisture gauges must typically be performed every:
   a) two weeks
   b) six months
   c) annually
   d) every two years

23. The NRC or agreement state nuclear materials license must be in the possession of the gauge operator at all times the gauge is in his/her possession? T or F

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

24. The Terracon radiation safety plan requires authorized gauge users to exercise suitable control over gauges at all times. T or F

25. Authorized gauge users of Terracon are also responsible for:
a) signing gauges in and out of the permanent storage location
b) wearing his/her assigned radiation monitoring badge
c) ensuring that gauges are used only for their intended purpose
d) all of the above

26. In accordance with the Terracon Emergency Action Plan, the first thing an authorized gauge user should do in case of a gauge accident is to:
a) isolate the area and deny entry to unauthorized personnel
b) panic
c) alert the media
d) none of the above

27. Backscatter density measurements are subject to error due to un-level, non-uniform surface conditions. T or F

28. Which two types of radiation are used by nuclear density/moisture gauges?
a) backscatter and direct transmission
b) non-ionizing and alpha
c) prone and supine
d) gamma and neutron

29. Each company or individual licensed to possess nuclear materials, including density/moisture gauges, are required to maintain radiation exposure of gauge operators and the general public "As Low as Reasonably Achievable" (ALARA). T or F

30. The sealed capsules in which the Americium 241 and Cesium 137 source material is contained blocks which forms of radiation?
a) alpha
b) gamma
c) beta
d) a and c above

31. The Americium 241 source contained in nuclear density/moisture gauges emit fast neutrons which are used to measure:
a) fabric
b) moisture
c) density
d) surface roughness

32. Failure to lock the source rod into the calibrated notch position can introduce significant error to density readings. T or F

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

33. Buried boulders or debris can result in elevated direct transmission density measurements.
    T or F

34. Failure to position the source rod against the side of the test hole can reduce density measurement by up to:
    a) 0.5 lb/ft^3
    b) little to nothing
    c) 70 lb/ft^3
    d) 25 lb/ft^3

35. Nuclear density/moisture gauges must be locked in the shipping case and secured against theft when not actually in use. T or F

36. The U.S. Department of Transportation assigns UN numbers to hazardous materials such as nuclear gauges. T or F

37. How many Radioactive II hazard labels are required on a nuclear density gauge shipping container?
    a) two.
    b) one.
    c) none.
    d) two on each side.

38. Hazardous substances may be legally transported by highway only when documented by a properly completed____________________?
    a) hazardous waste manifest.
    b) chain of custody form.
    c) hazardous materials shipping paper.
    d) FHWA nomenclature document.

39. Nuclear density/moisture gauges may not be legally transported aboard a passenger aircraft.
    T or F

40. The Proper Shipping Name for a nuclear density/moisture gauge is:
    a) Troxler Electronic Labs, Inc., Model 3411-B
    b) Radioactive Material, Yellow II
    c) R.Q., Radioactive Material, Special Form, N.O.S.
    d) Caution: Radioactive Material

41. Radioactive vehicle placards are not required on a vehicle transporting nuclear density/moisture gauges? T of F

42. A nuclear density gauge may be legally shipped in a wooden or cardboard crate if you can't find the shipping container supplied by the manufacturer. T or F

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

43. A 24-hour emergency response telephone number is required on all hazardous materials shipping papers? T or F

44. Which of the following documents must *ALWAYS* be carried in the nuclear density/moisture gauge shipping case?
    a) copy of nuclear materials license
    b) copy of most recent leak test
    c) copy of operators manual
    d) all of the above

45. In the event of an accident, the FIRST thing an authorized gauge technician should do is:
    a) isolate the area and deny entry to unauthorized personnel
    b) panic
    c) permit all equipment operating in the area to leave
    d) run to nearest telephone and call the police

46. To which Hazard Class/Division are radioactive materials assigned?
    a. Class 3
    b. Class 1
    c. Class 7
    d. Class 9

47. The Terracon Nuclear Materials Emergency Action Plan is considered a part of the DOT Hazardous Materials Shipping Paper. T or F

48. According to DOT Hazardous Materials Regulations, Hazardous Materials Shipping Papers must be kept within reach of the driver at all times during hazardous materials transport. T or F

49. An employee may prepare their own hazardous materials package MARKINGS, provided the proper information is printed durably and legibly. T or F

50. Cargo airlines will require a properly completed IATA "Shippers Declaration for Dangerous Goods" form in order to transport a nuclear gauge by cargo aircraft. T or F

_______________________________ ________ ________
Terracon Employee Name (Please Print) Date Office

____
Signature

Practical Examination --Demonstration of Competency ________ ________
Pass Fail

THE TERRACON COMPANIES, INC.
RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

1. Fast neutron best slowed by:
   a) lead
   b) hydrogen (page 5)
   c) asbestos
   d) air

2. Atoms of the same element having different numbers of neutrons are called:
   a) isotopes (page 4)
   b) surrogates
   c) gluons
   d) quarks

3. The process by which radioactive isotopes become stable is known as:
   a) distention
   b) radioactive decay (page 5)
   c) serendipity
   d) synchronous

4. The rate of radioactive decay of a radioactive isotope is usually expressed in terms of its:
   a) atomic number
   b) neutron flux density
   c) half-life (page 6)
   d) field strength

5. The amount of shielding required to stop one-half of the radiation emitted by a gamma radiation source is referred to as the:
   a) half-value layer (page 7)
   b) triple point
   c) majority interest
   d) Curie

6. The quantity of ionizing radiation of any type which, when absorbed by man produces a physiological effect equivalent to that produced by the absorption of one Roentgen of X- or gamma rays is the:
   a) Roentgen
   b) Rad
   c) Rem (page 8)
   d) Calorie

7. Radiation measuring instruments usually provide a measurement of either dose or ____________________.
   a) source material
   b) Curies
   c) magnetic density
   d) dose-rate (page 13)

8. The film badge is a commonly used as a method of measuring the accumulated radiation dose received by an individual. T or F **(page 13)**

9. Radiation dose is equal to the dose-rate multiplied by the duration of exposure, or, **Dose = Dose-Rate x Time Exposed**. What is the dose received by an individual exposed to 0.5 millir
   a) 400 millirems
   b) 3 rems/hr
   c) 7.5 millirems (page 14)
   d) 4 rems

10. The three primary principles employed to protect individuals against radiation are:
    a) education, sodium and water
    b) time, distance and shielding (page 14)
    c) glass, monitoring and regulation
    d) soil, asphalt and concrete

11. The intensity of radiation at any distance from a radioactive source decreases in accordance with the:
    a) Peter Principle
    b) Compton Effect
    c) Prime Rate
    d) Inverse Square Law (page 14)

12. The maximum allowable radiation dose limit for adult workers over the age of 18 years is:
    a) 5,000 millirems/year
    b) 10 microcuries/year
    c) 5 rem/year
    d) Both a and c above (page 15)

13. Nuclear density/moisture gauges contain which of the following radioactive isotopes:
    a) Uranium 238 and Nickel 63
    b) Tellurium 127 and Rubidium 86
    c) Americium 241 and Cesium 137 (page 16)
    d) Strontium 90 and Plutonium 239

14. The sealed Cesium 137 source contained in nuclear density gauges emits what type of radiation:
    a) beta (page 16)
    b) gamma
    c) alpha
    d) krypton

15. The operator is responsible for nuclear/density moisture gauges at all times while it is in his/her possession. **T** or F **(page 25, 27)**

16. When the Cesium 137 source is in the safe, shielded position, a nuclear density/moisture gauge hanging down at arms length exposes the operator to what dose rate?
    a) 5 rems/hr
    b) 50 millirems/hr
    c) 3 curies/hr
    d) 0.5 millirems/hr (page 17)

17. Radioactive materials such as nuclear density/moisture gauges are regulated by:
    a) the U.S. Nuclear Regulatory Commission
    b) Agreement States
    c) the U.S. Department of Agriculture
    d) both a and b above (page 24)

18. The two methods of determining the density of construction materials with a nuclear density/moisture gauge are:
    a) backscatter
    b) seismic
    c) direct transmission
    d) both a and c above (page 20)

19. A standard count using the reference standard block supplied by the gauge manufacturer must NOT be conducted in a truck bed or on a tailgate. **T** or F **(page 22)**

20. Radioactive materials licenses issued by the U.S. NRC or an Agreement State will typically contain conditions requiring which of the following?
    a) radiation monitoring of gauge users
    b) periodic leak testing and inventory of licensed devices
    c) training of authorized gauge operators
    d) all of the above (page 24)

21. The Americium 241/Beryllium source in nuclear density/moisture gauges is a neutron source. **T** or F **(page 20)**

22. Leak tests of sealed sources contained in nuclear density/moisture gauges must typically be performed every:
    a) two weeks
    b) six months (page 25, 29)
    c) annually
    d) every two years

23. The NRC or agreement state nuclear materials license must be in the possession of the gauge operator at all times the gauge is in his/her possession? **T** or F **(page 25)**

24. The Terracon radiation safety plan requires authorized gauge users to exercise suitable control over gauges at all times. **T** or F **(page 25, 27)**

25. Authorized gauge users of Terracon are also responsible for:
   a) signing gauges in and out of the permanent storage location
   b) wearing his/her assigned radiation monitoring badge
   c) ensuring that gauges are used only for their intended purpose
   d) all of the above (page 25, 27, 28)

26. In accordance with the Terracon Emergency Action Plan, the first thing an authorized gauge user should do in case of a gauge accident is to:
   a) isolate the area and deny entry to unauthorized personnel (page 38)
   b) panic
   c) alert the media
   d) none of the above

27. Backscatter density measurements are subject to error due to un-level, non-uniform surface conditions. **T** or F **(page 20)**

28. Which two types of radiation are used by nuclear density/moisture gauges?
   a) backscatter and direct transmission
   b) non-ionizing and alpha
   c) prone and supine
   d) gamma and neutron (page 16)

29. Each company or individual licensed to possess nuclear materials, including density/moisture gauges, are required to maintain radiation exposure of gauge operators and the general public "As Low as Reasonably Achievable" (ALARA). **T** or F **(page 24)**

30. The sealed capsules in which the Americium 241 and Cesium 137 source material is contained; blocks which forms of radiation?
   a) alpha
   b) gamma
   c) beta
   d) a and c above (page 16)

31. The Americium 241 source contained in nuclear density/moisture gauges emit fast neutrons which are used to measure:
   a) fabric
   b) moisture (page 20-21)
   c) density
   d) surface roughness

RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

32. Failure to lock the source rod into the calibrated notch position can introduce significant error to density readings. **T** or F **(page 23)**

33. Buried boulders or debris can result in elevated direct transmission density measurements. **T** or F **(page 23)**

34. Failure to position the source rod against the side of the test hole can reduce density measurement by up to: **(page 23)**
    a) 0.5 lb/ft^3
    b) little to nothing
    c) 70 lb/ft^3
    d) 25 lb/ft^3

35. Nuclear density/moisture gauges must be locked in the shipping case and secured against theft when not actually in use. **T** or F **(page 25)**

36. The U.S. Department of Transportation assigns UN numbers to hazardous materials such as nuclear gauges. **T** or F **(page 33)**

37. How many Radioactive II hazard labels are required on a nuclear density gauge shipping container?
    a) two. (page 29, 36)
    b) one.
    c) none.
    d) two on each side.

38. Hazardous substances may be legally transported by highway only when documented by a properly completed__________________?
    a) hazardous waste manifest.
    b) chain of custody form.
    c) hazardous materials shipping paper. (page 35)
    d) FHWA nomenclature document.

39. Nuclear density/moisture gauges may not be legally transported aboard a passenger aircraft. **T** or F **(page 36)**

40. The Proper Shipping Name for a nuclear density/moisture gauge is:
    a) Troxler Electronic Labs, Inc., Model 3411-B
    b) Radioactive Material, Yellow II
    c) R.Q., Radioactive Material, Special Form, N.O.S. (page 36)
    d) Caution: Radioactive Material

41. Radioactive vehicle placards are not required on a vehicle transporting nuclear density/moisture gauges? **T** of F **(page 37)**

RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

42. A nuclear density gauge may be legally shipped in a wooden or cardboard crate if you can't find the shipping container supplied by the manufacturer. T or **(page 35)**

43. A 24-hour emergency response telephone number is required on all hazardous materials shipping papers? **T** or F **(page 36)**

44. Which of the following documents must *ALWAYS* be carried in the nuclear density/moisture gauge shipping case?
    a) copy of nuclear materials license
    b) copy of most recent leak test
    c) copy of operators manual
    d) all of the above (page 25)

45. In the event of an accident, the FIRST thing an authorized gauge technician should do is:
    a) isolate the area and deny entry to unauthorized personnel (page 38)
    b) panic
    c) permit all equipment operating in the area to leave
    d) run to nearest telephone and call the police

46. To which Hazard Class/Division are radioactive materials assigned?
    a. Class 3
    b. Class 1
    c. Class 7 (page 34, 36)
    d. Class 9

47. The Terracon Nuclear Materials Emergency Action Plan is considered a part of the DOT Hazardous Materials Shipping Paper. **T** or F **(page 36)**

48. According to DOT Hazardous Materials Regulations, Hazardous Materials Shipping Papers must be kept within reach of the driver at all times during hazardous materials transport. **T** or F **(page 29, 37)**

49. An employee may prepare their own hazardous materials package MARKINGS, provided the proper information is printed durably and legibly. **T** or F **(page 37)**

50. Cargo airlines will require a properly completed IATA "Shippers Declaration for Dangerous Goods" form in order to transport a nuclear gauge by cargo aircraft. **T** or F **(page 37)**

RADIATION SAFETY TRAINING FOR NUCLEAR DENSITY/MOISTURE GAUGE OPERATORS
FINAL EXAMINATION

______________________________ Terracon Employee Name (Please Print)   ________ Date   ________ Office

______________________________ Signature

Practical Examination --Demonstration of Competency   ________ Pass   ________ Fail

Question No.	Answer	Question No.	Answer
1	b	26	a
2	a	27	T
3	b	28	d
4	c	29	T
5	a	30	d
6	c	31	b
7	d	32	T
8	T	33	T
9	c	34	a
10	b	35	T
11	d	36	T
12	d	37	a
13	c	38	c
14	b	39	T
15	T	40	c
16	d	41	T
17	d	42	F
18	d	43	T
19	T	44	d
20	d	45	a
21	T	46	c
22	b	47	T
23	T	48	T
24	T	49	T
25	d	50	T

Facsimile Sheet

MISSION
MISSION
MISSION
Statement

The mission of Terracon is to be a leading consultant in the fields of geotechnical, environmental and materials engineering, and related services by:

- Providing diverse, technologically progressive and cost-effective services that are responsive to our clients' needs;
- Challenging our employees with professional opportunities while rewarding individual performance and teamwork; and
- Sustaining a viable practice as a client-driven, growth-oriented and employee-owned firm.

Terracon

Date:

To: BIL, BOI, CHE, COS, DAV, DEN FTC, GRE, LKZ, LNG, RFD, TOP, WIC

Office/Company:

Facsimile Number:

From: Gary K. Bradley

Office/Company: The Terracon Companies, Inc.
16000 College Boulevard
Lenexa, Kansas 66219

(913) 599-6886

Facsimile Number: (913) 599-0574

Subject: Potentially Defective Troxler Gauges

Number of Pages: 3 (including this sheet)

Comments: Troxler/NRC have issued the attached bulletin regarding Troxler 3400 series gauges. Please review & examine all gauges in your possession which may be affected. If damage is detected, return them to the manufacturer for repair ASAP!

Thank You - Gary K. Bradley
Corp. S&H Mgr./
Corp RSO

Bulletin Regarding Troxler Gauges with Extendable Source Rods

As a result of several recent incidents that have occurred in which the source cup has become detached from the extendable source rod of Troxler 3400 series gauges, Troxler is issuing this bulletin to assist users of surface/moisture gauges in using the gauges safely in compliance with the manufacturer's instructions. Troxler anticipates that this bulletin will help prevent additional source cup detachment incidents.

In order to simplify the manufacturing process, and not due to any incident, 3400 series gauges with serial numbers 13,300 and greater (i.e., manufactured since mid-1986) rely on a combination of a weld and a threaded design to secure the source cup to the source rod. With the addition of threads, the source cups will not dislodge unless the cups are physically unscrewed from the rod. The cases involving detached cups occurred with serial numbers below 13,300 which did not incorporate the threaded design and rely on the weld.

Upon notification of the above incidents, the Troxler Research and Development Department initiated an inspection program for gauges received for service and disposal. This inspection program looked at 310 gauges, 235 received for service and 75 received for disposal. No cracked rods were found in the gauges received for service. In the group of disposal gauges, two rods were identified as having a crack approximately 40% around the circumference. Further evaluation of these two rods demonstrated that they would not fail in normal use or typical accident conditions in the environment in which they are used. Several thousand gauges have been inspected over the last two years. Based on this inspection program Troxler has seen no signs of manufacturing defects. Inspections have revealed some cases of abuse of the equipment.

In an effort to reduce the likelihood of future source cup detachment incidents, Troxler, in cooperation with the North Carolina Division of Radiation Protection, has drafted several recommendations for gauge users as follows:

1. Gauges should be used in accordance with manufacturer's instructions found in the accompanying operator's manual. Under no circumstances should the source rod ever be driven or forced into the test material. A drill rod accessory is provided with the gauge to prepare a hole in the test material into which the source rod is inserted. If the user purchased a used gauge from someone other than Troxler which does not include the accessory, the user should contact Troxler to obtain a drill rod.

2. Troxler recommends that the user return the gauge to the manufacturer at least once every five years to allow the manufacturer to inspect the gauge and source rod for unusual wear and tear.

3. Troxler recommends that companies purchasing used gauges require an inspection by the manufacturer prior to purchase. Troxler takes no position regarding gauge inspections and source rod evaluations performed by anyone other than authorized Troxler Service Centers. Troxler recommends that any gauge involved in an accident be returned to the manufacturer for inspection prior to further use.

For further information, contact Michael Dishman, the Troxler Corporate Radiation Safety Officer, at (919) 549-8661.

TROXLER

Issued June 1996

TERRACON GAUGES WITH POTENTIALLY CRACKED SOURCE CUP HOLDERS

10/15/96

LOC	MFGR	MODEL #	SERIAL #
BIL	TROXLER	3411-B	6951
			8567
			8617
			10512
~~BLM~~	~~TROXLER~~	~~3241-C~~	~~2161~~
			~~9123~~
			~~10511~~
			~~13085~~
BOI	TROXLER	3411-B	4774
CHE	TROXLER	3411-B	10201
			10413
COS	TROXLER	3401-B	4257
			8240
DAV	TROXLER	3411-B	5656
DEN	TROXLER	3411-B	13161
FTC	TROXLER	3241-B	379
			2053
			10693
			12359
GRE	TROXLER	3411-B	4565
			5268
~~LAS~~	~~TROXLER~~	~~3241-C~~	~~2300~~
			~~4669~~
			~~12798~~
		~~4640~~	~~174~~
LKZ	TROXLER	3411-B	6242
LNG	TROXLER	3411-B	4350
			5223
			7100
			7107
			7371
RFD	TROXLER	3411-B	5468
TOP	TROXLER	3411-B	4520
			5250
WIC	TROXLER	3411-B	5146