FIELD DENSITY

COURSE CONTENT

FIELD DENSITY

Gauge Operations	Principles, Safety, Security & emergency Procedures
AASHTO T310	In-Place Density and Moisture content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
MoDOT TM35	Moisture Offset Factor for a Nuclear Gauge
Glossary	Glossary of Terms

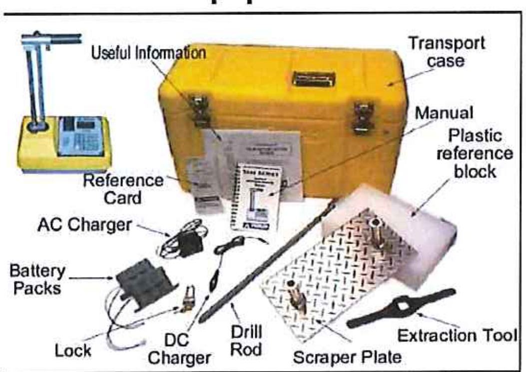
Nuclear Gauge Operation

Safety, Security & Emergency Procedures

Nuclear Gauge Operation

Safety, Security & Emergency Procedures

Equipment



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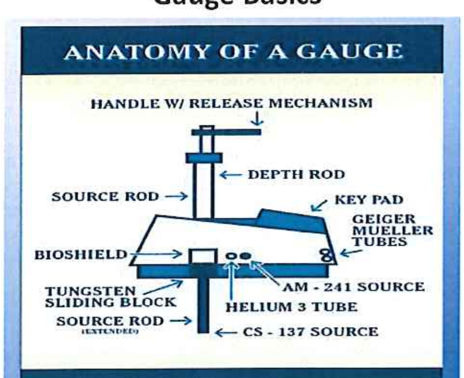
Gauge Basics



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Terminology

- **Radiation Exposure** – The particles and energy emitted/given off by radioactive material (Activity) and interacting with matter.
- **Contamination** – Radioactive material (energy or particles) in the wrong place, interacting/ionizing matter where it is NOT INTENDED!
  - The source in the gauge probe is not contamination, but a broken source outside the probe is.

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Exposure Control

- **ALARA** – As Low As Reasonably Achievable
- ALARA Concept Principles:
  - **Time:**
    - ➢Plan to spend as little as possible/practical around sources.
  - **Distance:**
    - ➢Increase distance from sources at available opportunities.
  - **Shielding:**

➢Place material between you and the source.

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Radiation Safety

ALARA & Gauge Operations

- **Time:**
  - ➢Think about actions in advance, have a plan.
  - ➢Plan your maintenance actions as well
- **Distance:**
  - ➢Keep distance in mind when gauge is in truck.
- **Shielding:**

➢Use available shielding

➢Report any defects to your company's safety officer.

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Radiation Safety

SHELDED

UNSHELDED

7

Gauge Theory

- Portable nuclear gauges have three major components:
  - 1. Radioactive source material
  - 2. Radiation Detectors
  - 3. Electronics to compute results

8

Security

- Portable gauges contain radioactive sources which are hazardous material – therefore, as an operator you are considered a Haz-mat employee!
- **All HAZMAT employees must be in possession of the licensee's gauge operating and emergency procedures.**
- **Gauge operating procedures detail the methods gauge operators take to limit their exposure to radiation, including the ALARA philosophy.**
- **Emergency procedures detail the steps to be taken in the event of damage or theft of the gauge.**

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Regulation on Gauge Security

- Each portable gauge licensee shall use a minimum of TWO independent physical controls that form tangible barriers to secure portable gauges from unauthorized removal, whenever portable gauges are not under the control and constant surveillance of the licensee.
- Tangible = Also means a substantial barrier/deterrent to gauge removal!

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Proper Storage at a Facility

- Storage inside a locked shed with secure outdoor area (such as a fence).
- Storage inside a locked room, within a secure building (which licensee controls).
- Storage inside a locked, non-portable cabinet inside a locked room (non-secure building).
- Gauge stored in a locked building and physically secured by a chain/cable in such a manner that the case can only be opened by removal of the cable.
- Securing transport case to inside structure of secured warehouse or storage facility.

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Proper Transport in a Vehicle

- Gauge secured with brackets, steel cables, or chains in a manner that the case can only be opened by removal of the bracket/cable/chain.
- Gauge stored in transport box in one of the following manners:
  - Box has two independent locks.
  - Chains/cables attached independently to vehicle in such a manner that the box can only be opened by removal of the chain/cable.
  - A combination of the above.
- Gauge in truck/camper shell, and is physically secured with a chain or cable so that the case can only be opened by removal of the chain or cable.

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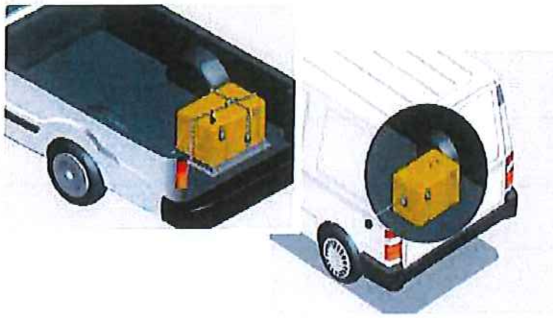
Three Lock Systems



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Access Control

- Designed to limit access of gauges to authorized personnel only.
- Gauge access keys should NOT be kept on the same ring with vehicle or other keys.

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Records – Log Books

- Maintains record of "Cradle to Grave" accountability required by Nuclear Regulatory Commission (NRC).
- Fill out (in ink) prior to departing office making sure all entries are legible.
- Date & time in/out, Signature, and Destination/Location are required.

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Field Operations

- Risks greatly increase when gauge is taken out of storage and taken to the job site.
- Line of Sight – gauge out of the transport case is kept within distance of the operator, (approximately 15 feet)
- Park vehicle in visible and/or secure location
  - Do not leave keys in an unattended vehicle.
  - Lock vehicle when away from the jobsite.
  - Think about security when parking away from the jobsite or office.

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Security - Transportation

- Employees using nuclear gauges are "Hazard Materials (HM) Employees" and are required to receive Hazard Materials Training.
- Training required within 30 days of Hazard Materials work and every 3 years.
- Training requirements: General Awareness, Function Specific, Security Awareness & Driver Requirements.

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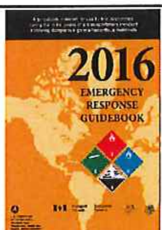
Security - Transportation



- **Communicate the Hazard!**
  - Shipping Papers
  - Markings ID #'s
  - Labels
  - Placards

These are designed to let public safety responders know that there is a dangerous material present so that extra precautions can be taken.

Use the ERG (Emergency Response Guidebook).

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Security - Transportation

- The shipping paper give the basic description and classification of the HazMat package.
- Shipping papers mush also contain detailed Emergency Procedures in the event of an incident or accidental release of the hazardous materials.

These papers must be kept in plain view, within the driver's reach – NO EXCEPTIONS!!!

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Security - Transportation

- **Shipping Papers for Nuclear Gauges must state:**
  - Owner of device
  - Proper shipping name & hazard class
  - RQ (for reportable quantity of Am-241)
  - UN identification number (UN-3332)
  - Radionuclide names (Cs-137, Am-241:Be)
  - Activity in package in SI units (0.3 GBq, etc.)
  - Label category & Transport Index (TI)
  - 24-hr emergency response telephone number & emergency response information.

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Labeling Requirements

- Exposure rates dictate use of Yellow-II
- 2 labels required, affixed on opposite sides of the transport case.
- Required label entries include radionuclides (i.e. Cs-137, am-241:Be), Activity in Standard International (SI)units, and Transport Index (TI).

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SAMPLE OF SHIPPING CASE LABELS

Front of Case

Back of Case

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Security - Transpiration

- Package requirements for gauges require shipment in approved Type A container. (Troxler Case)
- Package alterations ARE NOT ALLOWED!
- Container must be blocked and braced against shifting from normal driving conditions and placed as far away as possible from drivers and any passengers.
- No class 2.1 flammable gas (cylinders) are to be near nuclear gauges.
- Slowing or stopping is required at Railroad Crossings.

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Radiological Instrument Basics

- **Radiation & the Human Senses** – you can't see it, feel it, hear it, smell it, or even taste it. You can only detect and measure it using instrumentation.
- **Dosimeters/TLD's etc.** – Are like an odometer on a car, they only tell you Total Exposure for the radiation you have received.
- **Detection Instruments** – Are like your speedometer- they tell you how much exposure for the time of the exposure.

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Emergency Procedures

- **Emergency** – A combination of circumstances or resulting state that calls for immediate action.

- Possible Scenarios:
  - Damage to a gauge.
  - Accident involving vehicle in which a gauge is being transported.
  - Damage to a building in which a gauge is stored.
  - Lost or missing gauge.

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Emergency Procedures

- Portable gauges contain special-form, sealed radioactive sources.
- Radioactive material contained in the gauge does NOT post immediate health hazard, only hazard is from prolonged exposure or direct contact.
- No risk of explosion or fire.
- Will not kill you unless you ingest it.

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In the event of an emergency involving a portable nuclear gauge. . .

- Stop all equipment involved, including operators.
- Isolate area around gauge and source; rule of thumb is 15 feet in all directions.
- Treat any injured
  - Life-threatening injuries come first!
- Notify your Radiation safety Officer (RSO)!
  - For MoDOT: Lydia Brownell 573-526-4628

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After treating any injuries:

- Evaluate gauge condition
- Evaluate the source condition
- Conduct area/personnel surveys
- Set-up a control area as needed
- Make all notifications

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AASHTO T310

Density and Moisture Content of Soils and soil-Aggregate by Nuclear methods

(Shallow Depth)

AASHTO T 310

In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

Scope

Scope

- Specifications require that the field earthwork be compacted to a target density (% Compaction), related to the maximum density (Proctor).
- A nuclear density gauge is one device that is used to determine if the earthwork has met this requirement.
- Density readings for depths between 2" (50 mm) and 12" (300 mm) can be found.

2

Scope

- This test method describes the procedure for determining the in-place density and moisture of soil and soil aggregate by use of nuclear gauge.
- The density of the material may be determined by either:
  1. Direct Transmission
  2. Backscatter
  3. Backscatter/Air-Gap Ratio Method - Not covered in this certification.

3

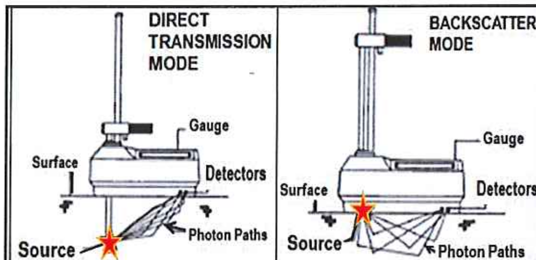
Scope

- The moisture of the material is determined only from measurements taken at the surface of the soil (i.e., backscatter)

- **Density** – The total or wet density of soil and soil-rock mixtures is determined by the attenuation of gamma radiation where the source or detector is placed at a known depth up to 12 inches while the detector(s) or source remains on the surface (Direct Transmission Method) or the source and detector(s) remain on the surface (Backscatter Method)

4

Scope



Direct Transmission	**Backscatter**
Measures the density of the material between the source and the surface.	**Measures the density of the material close to the surface (80% in top 2").**

5

Scope

- **Moisture** – The moisture content of the soil and soil-rock mixtures is determined by thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain at the surface.

- The water content in mass per unit volume of the material under test is determined by comparing the detection rate of thermalized or slow neutrons with previously established calibration data.

6

Significance

- The test method described is useful as a rapid, nondestructive technique for the in-place determination of the wet density and water content of soil and soil-aggregate.
- The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development.

Significance

7

- Density- Assumptions in the methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.
- Moisture – Assumptions in the method are that the hydrogen present is in the form of water as defined by AASHTO T265 and that the material under test is homogeneous.

Significance

8

- Test results may be affected by chemical composition, sample heterogeneity, and to a lesser degree, material density and the surface texture of the material being tested.

Significance

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Interferences

- In-Place density Interferences
  - The chemical composition of the sample may affect the measurement, and adjustments may be necessary.
  - The gauge is more sensitive to the density of the material in-close proximity to the surface in the Backscatter Method.

Interferences

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- Oversize rocks or large voids in the source-detector path may cause higher or lower density determination.
- Where lack of uniformity in the soil due to layering, rock, or voids is suspected, the test site should be excavated and visual examined to determine if the test material is representative of the full material in general, and if rock correction is required.
- Other radioactive sources should not be within **30ft** of the gauge in operation.

Interferences

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- In-Place Moisture Content Interferences:
  - Chemicals in the soil such as boron, chlorine, and minute quantities of cadmium, will cause measurements lower than the true value.
  - Other neutron sources must not be within **30 ft.** of the gauge in operation.

Interferences

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Safety

Safety

DO NOT USE GAUGE UNLESS PROPERLY TRAINED!!

- Anyone who operates a nuclear gauge is required to successfully complete a nuclear safety training class.

13

Radiation poisoning is very serious.

Safety

Always practice the "**ALARA**" principles to minimize exposure.

(**As** **L**ow **As** **R**easonably **A**chievable)

Four important facts to remember:

1. Time
2. Distance
3. Shielding
4. 2 Barriers

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Equipment

Equipment

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Equipment

- Nuclear Gauge
- Plastic reference standard
- Site preparation device – Shovel, Dozer, etc.
- Drill Rod
- Dry, fine sand for filling voids
- Operators instruction manual
- Small sledge hammer
- Extraction tool
- Scraper Plate(Template)

Equipment

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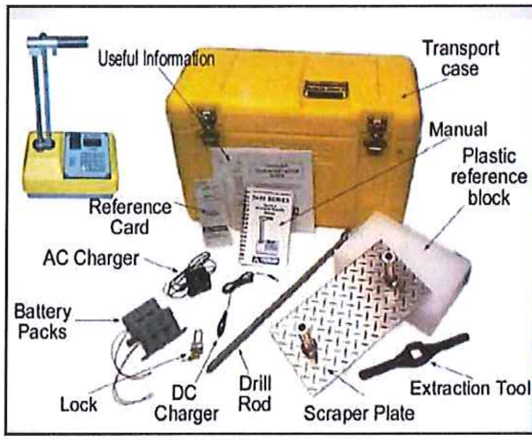

Equipment

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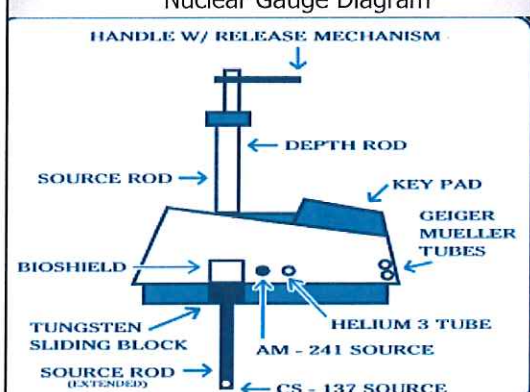
Nuclear Gauge Diagram



Equipment

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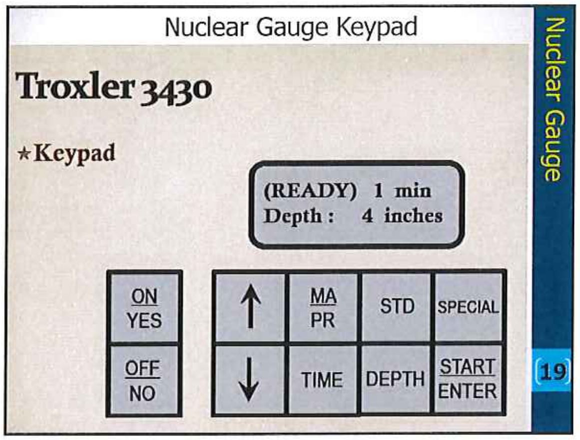

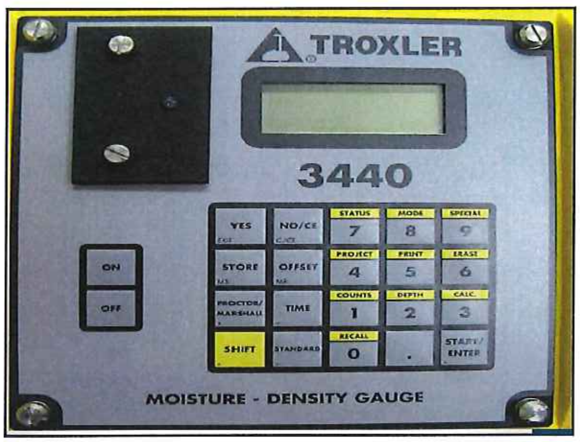

Nuclear Gauge - Description

- A sealed source of high-energy gamma radiation, such as cesium or radium.
- **Gamma Detector** - Such as Geiger-Mueller tube(s).
- **Fast Neutron Source** - A sealed mixture of a radioactive material, such as americium, radium, or californium 252, and a target material such as beryllium.
- **Slow Neutron Detector** – Such as boron trifluoride or helium-3 proportional counter.

Nuclear Gauge

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How it Works

- The gauge uses radiation, a gamma source and a gamma detector, to obtain several readings to determine wet density.
- To determine the dry density of a soil in place, it is also necessary to determine the moisture content.
- The nuclear gauge uses a second source, emitting fast neutrons, and a thermal neutron detector, which determines the intensity of slow or moderated neutrons to determine the moisture content.

Nuclear Gauge-How it Works

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- Moisture is determined by the relationship of nuclear count-to-mass of water per unit volume of soil.
- These readings are then used to calculate the in-place or dry density for soils and soil-aggregate mixtures.

Nuclear Gauge-How it Works

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Calibration of Gauge

- AASHTO T 310 requires that the gauge read within ± 1 lb/ft^3 on standard block(s) of material(s) with established density and moisture content.
- Calibration is performed by the Central Lab for MoDOT owned gauges.
- Calibration is performed by the manufacturer for industry owned gauges.
- Gauges will be calibrated once a year and when a gauge is not working correctly and/or giving irregular readings.

Nuclear Gauge-Calibration

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Standardization – At the Site

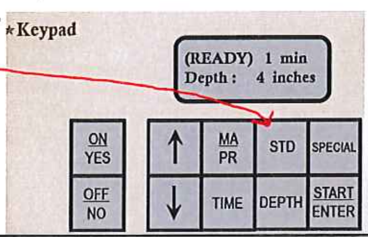
- Standardization must be performed daily or whenever gauge readings are suspect.
- Place the standard block on a dry, flat surface
  - 10' (3 meters) from any large vertical surface (i.e. concrete block wall).
  - At least **30 feet** (10 meters) from any other radioactive source.
  - "Sound" surface, in the same environment as the actual measurement counts.

For Troxler 3430, "Sound" defined as ≥100 lb/ft³.

Standard Count – On Site

Standard Count

- Take **4 one minute** repetitive readings.
  - On Troxler 3430's, when pressing the button for a standard count, the gauge *automatically* takes 4 one minute readings.



Standard Count

- Daily standard count must be within the following range from the average of the last 4 standard counts:

$$N_s = N_o \pm \left(1.96\sqrt{N_o / F}\right)$$

N_s = value of current standardization count
N_o = average of the past four values of Ns taken prior to usage
F = factory pre-scale factor, provided with the gauge (16 for a Troxler standard count)

Nuclear Gauge-Standardization

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Standard Count Example

Class Room Exercise

Data from Field Book	Density Count	Moisture Count
4 previous -	2758	667
3 previous -	2766	670
2 previous -	2748	668
1 previous -	2755	665
Average	2757	668

Today's Readings: Density= 2759 Moisture= 665

Q. Are todays readings in the range of previous readings recorded in the Field Book?

Nuclear Gauge-Standardization

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Standard Count - Density Classroom Exercise

N_o = **2757** for Density

N_s for Density is calculated as:

Calculate today's range **(N_s)**

$$N_s^S = 2757 \pm \left(1.96\sqrt{2757 / 16}\right)$$

Note: 16 is typical for a Troxler gauge

Nuclear Gauge-Standardization

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Standard Count – Moisture Classroom Exercise

N_o = 668 for Moisture

N_s for Moisture is calculated as:

Calculate today's range (N_s):

$$N_s = 668 \pm \left(1.96\sqrt{668/16}\right)$$

Note: 16 is typical for a Troxler gauge.

Nuclear Gauge-Standardization

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- $N_s = 2757 \pm (1.96\ \sqrt{2757/16}$
- Step One: 2757/16 = 172.3
- Step Two: $\sqrt{172.3}$ 13.1
- Step Three: 1.96 x 13.1 = 25.7 = 26
- For Step Four if the number is 5 or more round up and report the answer to a whole number.
- Step Four: 2757 ± 26
- 2757 - 26 = 2731
- 2757 + 26 = 2783

Density Calculation Steps

The Range is 2731 to 2783

Nuclear Gauge-Standardization

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Answer

- Density range is: **2731 to 2783**
- Moisture Range is: **655 to 681**
- Today's standard count is:
  - Density **2759** **this is in range.**
  - Moisture **665** **this is also in range.**
- If "Today's standard count" is outside of the calculated range, run another and recalculate including the previous count. Repeat until the count is within the range. **Note**: If after four counts, the gage does not pass, consult tech support.

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Offsets

- There are three offsets that are to be considered before testing.
  1. **Moisture Offset** – When measuring materials containing hydrogen not in the form of water, MoDOT TM 35 is used to set this.
  2. **Trench Offset** – When performing moisture and density measurements in a trench or near a large object the density or moisture may be effected due to reflecting gamma photons or neutrons.
  3. **Density Offset** – A density offset is used when measuring materials outside of the normal calibration parameters and often on asphalt materials with surface voids present.

Gauge Offsets

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Moisture Offset

- The moisture/density gauge measures the moisture content of material by detecting hydrogen present in the measurement area.
- Hydrogen may be present in material that is not in the form of water.
  - The presence of hydrogen in materials such as gypsum, mica, lime, phosphates, fly-ash, etc. may cause high moisture readings.
- A moisture offset is necessary to correct to the actual water content of the material.

Moisture Offsets

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- A few materials are considered to be neutron absorbers which may cause the gauge to read a falsely low moisture and may also require a moisture offset.
  - Examples of neutron absorbers are boron, salt, iron oxide, lithium, and cadmium.
- When testing aggregate bases or encountering contaminates, correct moisture using (K) offset MoDOT TM 35.

Moisture Offsets

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Trench Offset

Trench Offsets

- Normally the gauge only measures the moisture of the material below the gauge because other neutrons are not scattered back to the detectors. In a trench situation, the neutrons traveling above and beside the gauge may read the moisture in the trench walls also.

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Trench Offset Factor

Trench Offsets

- The trench offset needs to be used if the gauge is within 2 feet (0.6m) of the trench wall (or vertical structure) on any side of the gauge.
- Use the Trench offset factor when testing within 2 ft. (0.6m) of a wall in a trench.
- Refer to the gauge instruction manual for the proper procedure required to complete the Trench offset factor.

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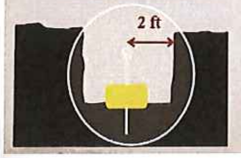
Trench Offsets

⋆Trench Offset

- ✓ Corrects moisture and shallow density readings
- ✓ Use anytime gauge is within 2 feet of a vertical soil structure



- ✓ Take a normal standard count outside trench
- ✓ Put gauge on standard block inside trench
  - Take a four minute reading with the rod in the "safe" position
  - (not a standard count)
- ✓ Record trench counts

Offset = Trench - Standard

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Density Offset

Density Offsets

- The difference between the gauge measured density and the alternative density measurement result (often a core).
- This value is used as the wet density offset in the gauge.

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Procedure

Procedure

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Density Testing Outline

Density Testing

1. Before Testing
2. Test Site Location
3. Prepare test site
4. Direct Transmission Method
5. Backscatter Method

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1. Before Testing

- Operator must be familiar with the gauge.
  - Gauge must be currently calibrated.
    - (Initially and then Annually)
  - Gauge papers and Radiation Training Card on hand and ready to travel to the test site.
  - Gauge is handled in a safe way for traveling and storing. (Secured and locks are in place)
  - Know how to operate gauge and put in lab data and run all tests.
  - Gauge has a good charge and ready to go.
  - Standard Counts Information, and log book on hand.
  - Check the equipment list to be sure all testing equipment is packed and ready to go.

Density Testing

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2. Site Selection

- Choose a test site that represents the test area.
- Avoid localized contaminations such as diesel spills, hydraulic oil, lime etc.
- Select location where the gauge will be 6" (150 mm) away from any vertical projection.
- Look for a level area.
- Area cleared of people and moving vehicles.
- All radioactive sources are at least 30 feet away

Site Selection

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3. Prepare the Site

- Prepare the test site by removing all loose and disturbed material.
- Plane an area to maintain maximum contact between gauge and material being tested.
- Smooth an area to perform the test by use of shovel, dozer, scraper plate, etc.

Site Preparation

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Site Preparation

- The maximum void beneath the gauge shall not be more than **⅛"** (3 mm).
- Fill voids with sand or native material.
- Filled area shall not be more that **10%** of the surface area beneath the gauge.

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4. Direct Transmission Procedure

✓ Turn the gauge on to stabilize (Warm up).

⋆Drilling Hole

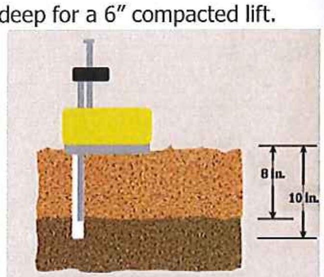
- ✓ **Place scraper plate on prepared test site**
- ✓ **Attach extraction tool and insert drill rod**
- ✓ **Step firmly on center of plate and hammer drill rod at least 2" deeper than test depth**
  - **Perpendicular to surface**

Direct Transmission Procedure 47

Direct Transmission Procedure

- Drive the gauge rod **2"** deeper than the lift to be tested.
  - Example: 8" deep for a 6" compacted lift.

Lift depth and Probe depth are always the same.



Example:
Lift thickness = 8 in.

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⋆Hole Drilling

- ✓ Remove drill rod with an upward, twisting motion

- ✓ Mark plate footprint and hole location

- ✓ Remove tools from area
  - ≈ 3 ft away

Direct Transmission Procedure

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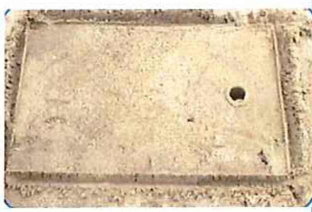
- Simply etch around the base of the scraper plate before picking it up.



Direct Transmission Procedure

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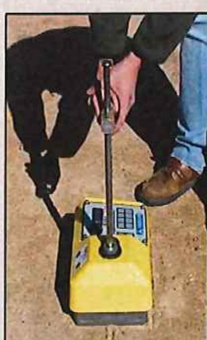
⋆Before Testing

- ✓ Check gauge parameters
  - Depth (lift thickness)
  - Time (1 minute)
  - Max. Density (proctor)
- ✓ Place gauge in footprint
  - Align rod with hole marks
- ✓ Lower rod to test depth
- ✓ Snug gauge back against hole
  - Check contact with soil



Direct Transmission Procedure

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Snug the gauge in the direction that will bring the side of the probe in contact with the side of the hole.
(Move towards the center of gauge.)

Direct Transmission Procedure

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- Perform any calibration offsets to determine wet density of material being tested.
- Operate according to manufacturer's instructions.

Direct Transmission Procedure

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Take 1 or more one minute readings to determine: % Compaction
Dry Density
% Moisture

Direct Transmission Procedure

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- Newer gauges display the maximum dry density (DD) after taking the readings.

Record the readings.

Direct Transmission Procedure

55

- The gauge may be rotated about the axis of the probe to obtain additional readings. Prepare the site in advance to accommodate a larger testing area for this.

56

- Always return the source rod to the "SAFE" position before lifting the gauge from the test site to minimize exposure to the technician.

Sometimes referred to as the "Peeker" method.

Direct Transmission Procedure

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5. Backscatter Method

- Used when properties of first few inches are concerned (i.e. overlays).
- The more dense the material, the smaller the volume tested.

Backscatter Method

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Backscatter Procedure

- Clear the area of people and equipment.
- Turn the gauge on, allow to warm up.
- Set the gauge to Backscatter (BS) position
- Find a smooth place on the asphalt 30 feet away from other radioactive sources.
- Place gauge on prepared site.
- Several trial seatings may be necessary.
- Operate device according to the manufacturer's instructions.
- Take 1 or more one minute readings to determine the wet density.

Backscatter Method

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Summary of Testing

- Gamma rays emitted by the source are absorbed by the soil, scattered in the soil, and will pass through the material.
- The detector counts the rays that pass through the material and this number is relayed to the master control, called a scalar, by means of electrical impulses.

Summary of Testing

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Summary of Testing

- For Density-
  - The number of rays counted depends on the density of the material.
  - The higher the density of the material the lower the gamma ray count.
- For Moisture-
  - Fast moving neutrons are slowed by hydrogen atoms and counted.
  - The lower the number of neutrons counted the lower the amount of moisture.

61

Calculation of Results

Calculations

Direct Measurements

- ✓ **Wet Density**
- ✓ **Moisture Content**

Calculated Values

- ✓ **Dry Density**

$$DD = \frac{WD}{\left(1 + \frac{MC}{100\%}\right)}$$

- ✓ **% Compaction**

$$\% PR = \frac{Gauge\ DD}{Proctor\ DD}\ x\ 100\%$$

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Calculation of Results

- If dry density is required, the in-place water content may be determined by using the nuclear methods described herein, gravimetric samples and laboratory determination, or other approved instrumentation.
- If the water content is determined by nuclear methods, use the gauge readings directly, or subtract the lbm/ft^3 (kgm^3) of moisture from the lbm/ft^3 (kgm^3) of wet density, and obtain dry density in lbm/ft^3 (kgm^3).

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Calculation of Results

- If the water content is determined by other methods, and is in the form of percent, proceed as follows:

$$d = \frac{100}{100 + w} X (m)$$

d =	**Dry density in lb./ft³ (kgm³)**
m =	**Wet density in lb./ft³ (kgm³)**
w =	**Water as a percent of dry mass**

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Calculation of Results

- Percent Density:
- It may be desired to express the in-place density as a percentage of some other reference density, for example, the laboratory densities determined in accordance with AASHTO T99, AASHTO T180, or MoDOT TM40 (AASHTO T272).
- This relation can be determined by dividing the in-place density by the laboratory reference density and multiplying by 100.

65

Calculation of Results

% Compaction Example

- Correct proctor value was active in the gauge at the time of testing and true moisture content returned by the gauge

$$\%\ Compaction = \%\ PR\ from\ Gauge$$

- Proctor value was not available at the time of testing

$$\%\ Compaction = \frac{Gauge\ DD}{Proctor\ DD}\ x\ 100\ \%$$

66

Sample Calculations

Calculation of Results

⋆Field Test

This job required:
≥ 95 % Compaction
Optimum Moisture ± 3%

Gauge DD	113.0 lb/ft³ @ 12.4 %
Proctor	115.9 lb/ft³ @ 14.0 %

Does this site meet density and moisture requirements ?

$$\% \, Comp = \frac{113.0}{115.9} \, x \, 100 = 97.5 \, \%$$

Yes

Gauge MC is within 3% of proctor MC

67

Report

- Report:
  - Standardization and adjustment data for the date of the tests
  - Make, model, and serial number of the test gauge.
  - Name of the operator(s)
  - Date of last instrument calibration or calibration verification.
  - Test site identification.
  - Visual description of material tested.
  - Test mode (backscatter or direct transmission)
  - Wet and dry densities in (kg/m³) or unit weights in lb/ft³.
  - Water content in percent of dry mass or dry unit weight.
  - Any adjustments made in the reported values and reasons for the adjustments. (offsets, etc....)

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Common Testing Errors

Common Testing Errors

- Soil chemical composition.
- Soil not homogenous.
- Equipment not calibrated properly.
- Surface texture too rough.
- Testing too close to vertical wall.
- People or equipment too close.

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Common Test Errors

- Not correcting for moisture using (K) offset MoDOT TM 35, when testing base material.
- Testing areas with the presence of soil contaminates, without correcting moisture using (K) offset MoDOT TM 35.
  - Materials containing hydrogen and neutron absorbing materials.

Common Testing Errors

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MISSOURI DEPARTMENT OF TRANSPORTATION
NUCLEAR DENSITY-MOISTURE TEST DATA

☐ Soil

☐ Type ______ Base

Contract ID ________________
Job No. ________________ Route ______ County ______________ Report No. ______

Date								
Station								
Location R/L – CL								
Dist. Below Profile Gr.								
Standard Test No.								
*A – Test Number								
*B – Probe Depth								
*C – Density Standard Count								
*D – Moisture Standard Count								
*E – Moisture Correction								
*F – Dry Density = DD								
*G – Wet Density = WD								
*H – Standard Density								
*I – % Compaction = PR								
*J – Minimum Density Required								
*K – % Moisture								
*L – Optimum Moisture								
% Moisture Specified	Min.							
	Max.							
Retest of	Test No.							
	Date							

Remarks: ____

____

____

________________________ Inspector

* See page 2 of form for more information on testing procedures.

Distribution: RE File

MISSOURI DEPARTMENT OF TRANSPORTATION
DENSITY-MOISTURE TEST DATA NUCLEAR

A – Consecutive, by material per project
B – Reading on display must match probe position
C – Read direct from display – Daily Standard
D – Read direct from display – Daily Standard
E – Record correction for current material
(Reference page 3–4 Troxler Manual
F – Record from display for current test
G - Record from display for current test
H – Provided by Materials for current material
I – Record from display for current test
J – Provided in contract documents or specifications
K – Record from display for current test
L – Provided form Materials for current material

DAILY CHECK LIST

1. Two different keys are needed
2. Wear badge
3. Make entry in sign out diary
4. Place travel papers on truck dashboard in plain view within driver's reach (transport gauge in locked box only)
5. Warm up machine 10 minutes – Set on plate with probe opposite butt plate
6. Take standard count – record standard counts in diary. Follow instruction manual.
   1% Density Deviation, 2% Moisture Deviation
7. Enter proctor value from materials
8. Enter applicable moisture correction – See pages 3-4 in Troxler Manual
9. Sign back in at end of day and clean equipment

TROUBLE SHOOTING

Do not charge batteries until "low battery" appears (2-3 hours remaining)

If the display reads "GM Tube A Error, Service Required", remove and replace fuse; retry entry.

See 203.5 of the Engineering Policy Guide for information on testing with Nuclear Moisture-Density Gauges.
See http://scweb4/hq/co/radiation for routine maintenance issues.

Battery Voltage: 3.6, Normal
3.35-3.4, Battery low but serviceable
3.25-Below, No service

Technical Advice: 573-526-4628

AASHTO T 310: Density and Moisture Content of Soils and Soils-Aggregate by Nuclear Methods
PROFICIENCY CHECKLIST

Applicant: ______________________________

Employer: ______________________________

Trial#	1	2
Make sure gauge is calibrated, charged, lab data, or offsets entered if any.		
Standardization		
1. Performed at start of each day's use		
2. Permanent records of data retained		
3. Performed with equipment at least 10m (30ft) from other radioactive sources, and clear of large masses of water or other items which may affect reference count		
4. Using reference standard, at least four repetitive readings taken at normal measurement period, and mean obtained.		
5. Procedure recommended by gauge manufacturer used to determine compliance with gauge calibration curves or – Equation 1 used to determine standardization		
Preparing the test site		
1. All loose, disturbed and additional material removed as necessary to expose top of material to be tested		
2. Horizontal area sufficient in size to accommodate the gauge prepared by planeing the area smooth with plate or suitable tool to obtain maximum contact between gauge and material tested		
3. Native fines or fine sand used to fill voids as necessary, for surface area less than 10% beneath the gauge.		
4. The depth of filler does not exceed approximately 1/8" (3mm)		

AASHTO T 310: Density and Moisture Content of Soils and Soils-Aggregate by Nuclear Methods
PROFICIENCY CHECKLIST
(CONT.)

Trial#	1	2
Direct Transmission Method		
1. Hole made perpendicularly to prepared surface using guide and drill rod.		
2. Hole is at least 2 in. (50mm) deeper than the lift to be tested.		
3. Remove the drill rod and mark around the scrapper plate		
4. Remove all equipment from the test area except the gauge		
3. Placed the gauge on marked area, ensuring maximum surface contact		
4. Source rod lowered into hole to same depth of the lift being tested		
5. Gently move the gauge in the direction that will bring the side of the probe in contact with the side of the hole leaving no gap between the probe and the soil being tested. Note: A rod containing radioactive sources shall not be extended out of its shielded position prior to placing it in the test hole		
6. Take one or more 1-minute readings secured and recorded		
7. In-place wet density determined by calibration curve previously established, or gauge read directly if so equipped. Note: The gauge may be rotated about the axis of the probe to obtain additional readings		
Backscatter Method		
1. Clear the area of people and equipment		
2. Turn the gauge on, allow to warm up		
3. Set the gauge to Backscatter mode		
4. Find a smooth place on the asphalt 30 feet from other radioactive sources		
5. Prepare the site		
6. Gauge seated firmly on prepared test site		
7. All other radioactive sources kept at least 10m (30ft) away from gauge		
8. Gauge set to Backscatter (BS) position		
9. Take one or more 1-minute readings secured and recorded		
10. In-place wet density determined by use of calibration curve previously established, or gauge read directly if so equipped		

PASS PASS

FAIL FAIL

Examiner: ______________________ Date: ______________

MoDOT TM35

Moisture Offset Factor
for
Nuclear Gauge

MoDOT TM35

Moisture Offset (K) Factor for a Nuclear Gauge

Background & Overview

- This test method describes the procedure for determining a moisture offset factor to be applied to calibration curve values for moisture content determinations by nuclear gauges in soil, soil-aggregate and crushed stone bases.
- Also Known as the "K" factor.

Do not confuse this with the Proctor Standard.

Background & Overview

2

Terminology

- **Heat Dried Moisture** - moisture content test by AASHTO T 265 ($\%M_{lab}$)
- **Nuclear Moisture** - uncorrected moisture content by nuclear gauge ($\%M_{gauge}$)
- **K** - Moisture Offset factor
- **% Moisture** – corrected moisture reading of soil or aggregate as determined by nuclear gauge.

Terminology

3

Equipment

Equipment

- Nuclear gauge
- Air tight sample container and other sample collection equipment
- Oven capable of 230 ± 9°F (110 ± 5°C)
- Scale capable of weighing 2 Kg
- Other drying equipment - pans, gloves, brushes, etc.

4

Safety

Safety

- Anyone who operates a nuclear gauge is required to successfully complete a nuclear safety training class.
- Always practice the "**ALARA**" principle to minimize exposure.

(**A**s **L**ow **A**s **R**easonably **A**chievable)

- Four important facts to remember:
  1. Time
  2. Distance
  3. Shielding
  4. 2 Barriers

Keep the gauge body between you and the source rod to reduce exposure.

5

Procedure

Procedure

1. Using a calibrated gauge select at least 4 testing sites for each soil or aggregate type.
2. Make sure **moisture offset** is disabled in the machine.
3. Perform nuclear density tests and percent moisture test for each location.
4. Record percent moisture for each location. This is $\%M_{gauge}$ for each sample.

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5. Obtain field sample from each test site for lab testing. Take sample from material located between source rod and detectors to a depth of 5" but not into underlying layers.
6. Sample weight should weigh 1000 g (2.2 lb) for sample with particles ¼ inch or less and 1500 g (3.3 lb) for sample with particles larger than ¼ inch present.
7. Dry the field samples.
8. Calculate heat dried moisture content, this is the $\%M_{lab}$ for each sample. (AASHTO T265 performed by the lab)

Procedure

(7)

Calculations

- Calculate the average percent nuclear moisture and the average heat-dried moisture from the test sites for each soil/aggregate type.

$\%M_{gauge}$	$\%M_{lab}$
8.5	8.8
8.4	8.6
8.5	8.6
8.3	8.5
Avg. 8.4	Avg. 8.6

Calculations

(8)

Calculations

- Calculate the moisture offset factor (K) for use in 3430 gauge as follows:

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

- $\%M_{lab}$=Average heat-dried moisture
- $\%M_{gauge}$ = Average % nuclear gauge moisture reading
- (K) can be either positive or negative.
- Report to the nearest tenth 0.1.

Calculations

(9)

Classroom Exercise

- Example:

$\%M_{gauge}$	$\%M_{lab}$
8.5	8.8
8.4	8.6
8.5	8.6
8.3	8.5
Avg. 8.4	Avg. 8.6

- Calculate *K* Factor to the nearest tenth:

Calculations

10

Procedures

- Enter the moisture offset (K) into the nuclear gauge per the owner's manual.

  Can be ignored if ± 0.5 pcf or less.

- Remember that each Nuclear Density Gauge is Unique. The amount of radiation emitted is different, gauge to gauge.
- A (K) factor derived on one gauge cannot be used for another.

Calculations

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Reporting

- **(*K*) can be either positive or negative.**
- **Report to the nearest tenth 0.1.**
- Record moisture correction (K) factor calculations in a bound field book that is stored with the gauge.
- Record in weekly compaction reports.

Reporting

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Common Errors

- Not using a calibrated nuclear gauge
- Not using enough testing sites
- Not checking correction factor on each new soil type (ie: rock, sand, clay, silt, gumbo)
- Not using an air tight sample container to transport sample to lab
- Not drying sample to oven-dry condition
- Mixing soil/aggregate types

13

Calculations

- Proficiency

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

%M_{gauge}	%M_{lab}
15.5	15.8
15.4	15.6
14.9	14.6
15.3	15.5
Avg.	Avg.

$$K =$$

304.2 Material Inspection for Sec 304

304.2.1 Scope

This guidance establishes procedures for inspection and acceptance of material used in aggregate base. Aggregate for use in base courses is to be inspected in accordance with Aggregate for Base.

304.2.2 Apparatus

The apparatus and materials required are listed in General Requirements for Material.

304.2.3 Procedure

304.2.3.1 Quality Control/Quality Assurance (QC/QA)

The contractor (QC) shall control operations to ensure the aggregate base, in place, meets the specified requirements for density, thickness, gradation, deleterious and plasticity index. Tests are to be taken at random locations designated by the engineer. The inspector (QA) shall take test, at random locations and at a reduced frequency, to accept the contractor's results.

304.2.3.2 Compaction Standard

Aggregate base course construction, except as noted in the Standard Specifications, requires that a certain density be achieved. In order that this density can be checked in the field, a sample must be submitted to the Laboratory for standard maximum density determination. The contractor is also required to determine the compaction standard. The contractor's compaction standard shall be within 3.0 pounds of the compaction standard determined by the Central Laboratory. When the contractor's compaction standard compares favorably with the engineer's standard, the contractor's standard will be used as the basis of subsequent density tests.

The inspector shall obtain representative samples and submit two full sample bags of material in accordance with the procedures outlined in General Requirements for Material. In addition, the sample record in SiteManager shall request that a compaction standard test be performed.

304.2.3.3 Random Sampling

The inspector shall generate random numbers for both the inspector's and contractor's sampling, for the testing of each "lot" of material. A "lot" is defined in Sec 304.4.1. For example, a "lot" for the contractor's determination of gradation and deleterious is defined as 2,000 tons or a days production, whichever is greater.

The inspector shall generate the numbers either using a random number table or with a random number generator on a calculator or computer. Using a random number generator is the preferred method.

The inspector shall generate two (2) random numbers for each lot. One to determine the longitudinal offset and one for the transverse offset. Only one set of random numbers needs to be determined for the Density and Thickness "lot". Determine the density and thickness of the base at the same location.

304.2.3.4 Sampling

Samples for gradation, deleterious and Plasticity Index (PI) shall be taken at the roadway, behind the placing operation, prior to compaction. Care should be taken to not contaminate sample with sub-grade material when extracting a sample from the roadway. The recommended sample size is outlined in General Requirements for Material. The contractor's QC sample shall be large enough so that after removal of the material for the QC tests, all retained material from the QC's final split will be an adequately large amount for comparison testing.

304.2.3.5 Testing

Tests are to be run in accordance with the applicable test methods at the frequency listed in Sec 304.4.1. Please note that the frequencies listed are minimums. If material is approaching specification limits or if problems are encountered the inspector should increase the testing frequency.

Inspectors shall test one of the contractor's retained QC samples at the following frequencies:

Test	Frequency
Gradation and Deleterious	1 per project with a minimum of 1 per week and at least 1 per 16,000 tons
PI	1 per project with a minimum of 1 per week and at least 1 per 80,000 tons

For determination of thickness a rule with suitable graduations should be used to accurately measure the material to be inspected.

For the determination of density the inspector should use AASHTO T 310, Direct Transmission, for wet density. In order to determine the wet density the inspector must have first submitted a sample for the determination of the Compaction Standard. At the start of the job, a moisture-offset factor shall be determined in accordance with MoDOT Test Method T35.

For retained samples, the contractor's test results and the engineer's test results shall compare within the limits specified.

304.2.3.6 Failing Tests

Procedures for failing test results are outlined in Sec 304.4.

304.2.4 Trimmed Base

Trimmed base may be reused as base material but must be checked for specification compliance prior to use. The material should be stockpiled and held pending testing. Material not meeting gradation can be reconditioned. Material that has been contaminated to such an extent that it no longer complies with the specification cannot be used

106.3.2.35 TM-35, Moisture Offset Factor for a Nuclear Gauge

From Engineering Policy Guide

This test determines the moisture offset factor to be applied to the calibration curve values for moisture content determinations by nuclear gauges in soil, soil-aggregate and crushed stone bases.

Crew takes a soil sample on an interstate to determine soil conditions and how much rock is beneath the surface.

106.3.2.35.1 Equipment

(a) Nuclear moisture-density gauges meeting the apparatus and precision requirements of AASHTO T310.

(b) Equipment specified by AASHTO T205, paragraphs 2.2, 2.3 and 2.4.

106.3.2.35.2 Procedure

A correction factor for use with the moisture calibration curve shall be determined as follows:

(1) No fewer than four tests[a] are required to establish a moisture offset factor. These tests should be obtained from material typical of that to be tested and should be randomly selected over the largest practical area of material positively identifiable as the material to be tested. For soils, the tests may be performed in cuts behind the earth movers.

> [a] The required number of tests is based upon statistical considerations which include a selected confidence level of 99%, a selected confidence interval of 0.5 pcf and a standard deviation of 0.35 pcf for nuclear moisture test values as determined by Research Study 74-2.

(2) At each random site, perform a nuclear wet density and moisture test in accordance with AASHTO T310 Direct Transmission and obtain a moisture sample for heat drying. Obtain the moisture sample and heat dry as follows:

> a. Select the sample from that material located between source and detectors during the nuclear determinations.
> b. The moisture sample should weigh from 1000 g (2.2 lb) to 1500 g (3.3 lb). The higher weight sample should be obtained when particles larger than 1/4 in. are present. The sample should be obtained to a depth of 5 in. (127 mm) except that the depth should be reduced so as to not exceed the thickness of any layer under test. (Note: The nuclear meter has not been evaluated in crushed stone bases where the lift was less than 4 in. thick.)

c. Determine the moisture content of the total sample by heat drying at 110°C ± 5°C (230°F ± 9° F).

106.3.2.35.3 Calculations

(a) Determine the moisture offset factor from the average results of the 4 tests, as follows from Troxler Manual:

$$K = 1000 \times \frac{\%M_{LAB} - \%M_{GAUGE}}{100 + \%M_{GAUGE}}$$

Where:

K = Moisture Offset Factor
$\% M_{LAB}$ = Percent moisture of heat dried sample
$\% M_{GAUGE}$ = Percent moisture of nuclear gauge

(b) Enter moisture offset factor (K) into gauge as outlined in the Operator's Manual.

(c) The offset factor can be ignored if 0.5 pcf or less.

MOISTURE OFFSET

The 3430 measures moisture by determining the hydrogen content of the soil and relating this to the water content. In some soils, there are compounds other than water that contain hydrogen as well as compounds that absorb neutrons. Both types of material will result in gauge readings that are different from the true soil moisture. If these compounds are suspected to be present in the soil, the gauge is equipped with a Moisture Offset for adjusting the readings.

The offset factor (k) is determined by comparing the moisture value of a laboratory sample with the moisture determined by a gauge reading. Use the following procedure:

1. Use laboratory methods to determine the moisture content of a sample taken at the measurement site. ($\%M_{LAB}$)

2. Take a gauge reading at the site. Record the readings. ($\%M_{GAUGE}$)

3. Calculate the offset factor (K).

$$K = \frac{\%M_{LAB} - \%M_{GAUGE}}{100 + \%M_{GAUGE}} \times 1000$$

Multiple samples and measurements may be taken. Calculate the average moisture of the samples and the gauge readings. These average values should be used for the offset factor calculation.

NOTE: If the "K" value is negative, a minus sign (-) may be entered by pressing the "Down" arrow prior to entering the first digit.

To perform a Moisture offset, press **SPECIAL**.

Press the "Down" arrow one (1) time and then press **ENTER** for the display:

Offset: Density (↑ ↓ or ENTER)

Press the "Down" arrow one (1) time and press **ENTER**.

Moist Offset OFF Want to enable?

Press **YES**.

K= 0.0 (↑ ↓ or ENTER)

Use the "Up" and "Down" arrows to change the numeric value.

NOTE: To input a minus (-) sign (for a negative offset), press the "Down" arrow <u>first!</u>

Press the **ENTER** key to change fields and exit.

The display will be:

Moist Offset ON

After the count time has elapsed, the display will be:

Wet Density

```
WD:   xxxxx
(Use ↑ ↓ keys)
```

Use the "Up" and "Down" keys to view the data.

Dry Density and Percent % Proctor)

```
DD:   xxxxx
% PR:  xxxxx  %
```

Moisture and % Moisture

```
Moist: xxxxx
% Moist: xxxx  %
```

$\%M_{GAUGE}$

Air Void and Void Ratio

```
Air Void:  xxxx %
Void Ratio: xxxx
```

Refer to the following page for the formulae used in calculating the above values.

% AIR VOIDS = 100 (1 - (Vs/Vt) - (Vw/Vt))

where:
Vs = Volume of Soil
Vt = Total Volume
Vw = Volume of Water

= 100 (1 - (DD / SG(Dw)) - (M / (Dw)))

where: Dw = Density of Water

VOID RATIO = Volume of Voids / Volume of Soil
= (SG(Dw) - DD) / DD

Continue pressing the "Down" arrow for:

Moisture and Density Count Ratio

```
MOIST. CR:  xxxx
DENS. CR:  xxxx
```

Moisture and Density Counts

```
M Count:  xxxx
D Count:  xxxx
```

MISSOURI DEPARTMENT OF TRANSPORTATION
NUCLEAR DENSITY-MOISTURE TEST DATA

☐ Soil

☐ Type ________ Base

Contract ID ____________________
Job No. ____________________ Route ________ County ________________ Report No. ________

Date								
Station								
Location R/L – CL								
Dist. Below Profile Gr.								
Standard Test No.								
*A – Test Number								
*B – Probe Depth								
*C – Density Standard Count								
*D – Moisture Standard Count								
*E – Moisture Correction								
*F – Dry Density = DD								
*G – Wet Density = WD								
*H – Standard Density								
*I – % Compaction = PR								
*J – Minimum Density Required								
*K – % Moisture								
*L – Optimum Moisture								
% Moisture Specified	Min.							
	Max.							
Retest of	Test No.							
	Date							

Remarks: ____

____

____

____________________________ Inspector

* See page 2 of form for more information on testing procedures.

Distribution: RE File

MISSOURI DEPARTMENT OF TRANSPORTATION
DENSITY-MOISTURE TEST DATA NUCLEAR

A – Consecutive, by material per project
B – Reading on display must match probe position
C – Read direct from display – Daily Standard
D – Read direct from display – Daily Standard
E – Record correction for current material
(Reference page 3–4 Troxler Manual
F – Record from display for current test
G - Record from display for current test
H – Provided by Materials for current material
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J – Provided in contract documents or specifications
K – Record from display for current test
L – Provided form Materials for current material

DAILY CHECK LIST

1. Two different keys are needed
2. Wear badge
3. Make entry in sign out diary
4. Place travel papers on truck dashboard in plain view within driver's reach (transport gauge in locked box only)
5. Warm up machine 10 minutes – Set on plate with probe opposite butt plate
6. Take standard count – record standard counts in diary. Follow instruction manual. 1% Density Deviation, 2% Moisture Deviation
7. Enter proctor value from materials
8. Enter applicable moisture correction – See pages 3-4 in Troxler Manual
9. Sign back in at end of day and clean equipment

TROUBLE SHOOTING

Do not charge batteries until "low battery" appears (2-3 hours remaining)

If the display reads "GM Tube A Error, Service Required", remove and replace fuse; retry entry.

See 203.5 of the Engineering Policy Guide for information on testing with Nuclear Moisture-Density Gauges.
See http://scweb4/hq/co/radiation for routine maintenance issues.

Battery Voltage: 3.6, Normal
3.35-3.4, Battery low but serviceable
3.25-Below, No service

Technical Advice: Paul Hilchen 573-526-4628

MoDOT TM 35: Moisture Offset Factor for A Nuclear Gauge
PROFICIENCY CHECKLIST

Applicant: ____

Employer: ____

Trial#	1	2
1. Select at least 4 testing sites for each aggregate type		
2. Ensure that moisture offset is disabled or turned off in the machine		
3. Perform field nuclear wet density and moisture tests		
4. Record readings obtained and Avg. ($\%M_{gauge}$)		
5. At each test site obtain sample for moisture, retrieving material between source and detectors 2.2 lb. (1000gm) for ≤ ¼", 3.3 lb. (1500 gm.) > ¼"		
6. Dry sample per AASHTO T 265		
7. Record and Avg. ($\%M_{lab}$)		
8. Calculate "K" factor: $K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} X\ 1000$		

PASS PASS

FAIL FAIL

Examiner:_____________________________________Date:_________________

Glossary of Terms

Background Count – The naturally occurring radiation from lights, the sun, and many other sources.

Compaction – The reduction of voids in a soil mass. The densification of the soil mass by applying a force such as that delivered by the rammer.

Compaction Effort – The force applied to achieve compaction of a soil mass.

Density – The mass of the soil divided by the volume.

Dry Density – The density of the soil corrected for moisture content.

Fast Neutron Detector – An electronic device that counts neutrons as they pass through a special gas.

Fast Neutron Source – Each atom has a nucleus comprised of varying numbers of protons and neutrons. When a high-energy electron strikes a nuclei, on or more protons or neutrons are released. These neutrons are used to measure moisture content by a nuclear gauge.

Gamma Detector – An electronic device that converts electronic pluses caused by high energy electrons, passing through a special gas enclosed in a tube, into a numerical count.

Gamma Source – A radioactive material that emits high energy electron radiation, similar to x-rays commonly used in hospitals. The radiation is invisible and capable of passing through many millimeters of wood, soil or other material.

Homogenous – Of uniform structure and composition throughout.

Maximum Density – The dry density corresponding to the peak of the moisture-density curve. The highest density that can be achieved for a particular soil using a particular compactive effort.

Meniscus – The curved concave upper surface of a column of liquid in a tube.

Moisture Content – The ratio, expressed as a percentage, of the mass of the water in a given soil mass to the mass of the solid particles.

Moisture Density Curve – A smooth line connecting the points obtained from AASHTO T99 when plotted on a graph with moisture on the x-axis and density on the y-axis.

Moisture-Density Relationships – The interrelationship between density and changing moisture contents in a soil.

Optimum Moisture Content – The percent of free moisture at which a soil can reach its maximum density with a standard compactive effort.

Organic – Vegetable matter included in soil.

Percent Compaction – The ratio, expressed as a percentage, of the density of a soil to its maximum density.

Soil Mechanics – The study of engineering properties and behavior of soils.