Introduction Guide for Troxler Nuclear Density Gauges in New Zealand

M Petrovic

Groundtest Equipment
PO Box 13-026
Auckland 1643

+64 9 634 1509
marko@groundtest.co.nz
http://www.groundtest.co.nz/

Contents

Acknowledgements & References

Author acknowledges the time and expertise of Richard Burden and Robyn Myers for their assistance in discussing and reviewing this guide, and for providing valuable insights.

Reference sources:

- Compaction and Density Testing Course by Troxler Electronic Laboratories, Inc.
- Nuclear Gauge User Training- 3400 Series by Troxler Electronic Laboratories, Inc.
- Nuclear Gauge Operator Safety Training Course with Hazmat by Troxler Electronic Laboratories, Inc.

Abbreviations and acronyms

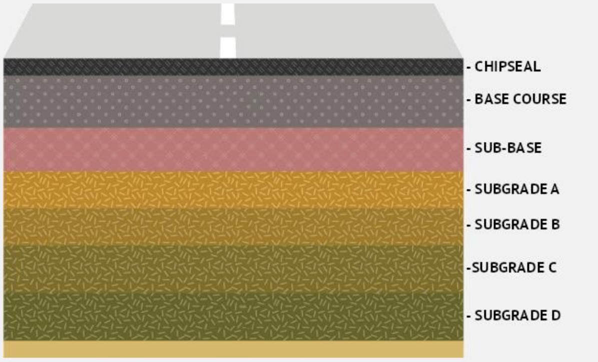
Troxler	Troxler Electronic Labs, Inc.
NDM	nuclear density meter
NZS	New Zealand Standard
MDD	maximum dry density
OWC	optimum water content
TNZ	Transit New Zealand
NZTA	New Zealand Transport Agency (Waka Kotahi)
AS	Australian Standard
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
TMSG	Theoretical Maximum Specific Gravity
Cs-137	Caesium-137 (radioactive isotope of Caesium)
Am-241	Americium-241 (radioactive isotope of Americium)
Be-9	Beryllium-9 (isotope of Beryllium)
Ci	The Curie (non-SI unit of radioactivity)
Bq	The Becquerel (SI derived unit of radioactivity)
ORS	Office of Radiation Safety (part of the Ministry of Health)
C12	Code of Practice for Sealed Radioactive Material
IANZ	International Accreditation New Zealand

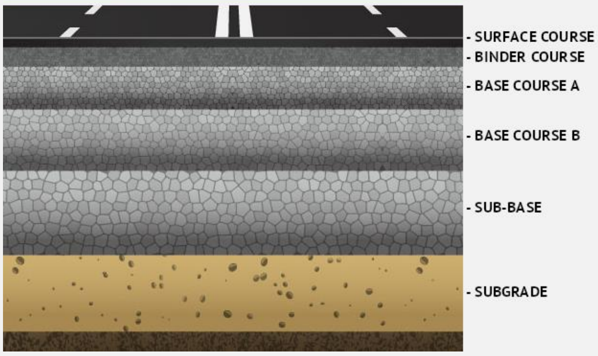
1. Introduction

Since 1958, Troxler has been the worldwide leader in the manufacturing of testing/quality control measurement equipment for the construction industry. Troxler name is especially recognized worldwide as the industry standard for Nuclear Moisture/Density Gauges, also referred to as Nuclear Density Meters (NDM) in New Zealand.

This guide will cover key details of NDM purpose, operation and safety requirements, but firstly it will touch up on the fundamentals of compaction and density testing in civil engineering industry. Before any structure can be built (road, building etc.) it is important to achieve adequate compaction of layers underneath. Failing to do so can result in catastrophic failures as material deforms under load, causing structures to settle.

Below are visual examples of different layers categorized for road construction (each road can be different).





To determine appropriate level of compaction for different layers, various lab tests are employed.
Most common one for soil is the Proctor test, also known as the Standard and Heavy compaction tests under NZS 4402.4.1.1 and 4402.4.1.2. These test methods cover the determination of dry density and water content relationship with the goal of plotting the Maximum Dry Density (MDD) and Optimum Water Content (OWC).

Below is a visual example of NZS standard compaction apparatus typically used for this lab test.

The highest density of most soils is achievable at the optimum water content (moisture level), which will vary depending on the soil type and size of the particles.
Soil will also require less compaction effort when it is near the OWC.

Contractors tasked with compaction of soil via roller compactors need to know how many passes to make depending on water content for the soil they're currently operating on. Proper compaction must be achieved before next layer of soil can be placed. An NDM quickly and accurately verifies the density and water content of compacted soil to ensure it adequately matches values established previously in a lab.

Below are visual examples of compactors suitable for compacting different types of soil.




For aggregate, the [TNZ B/02:2005 specification] is used for the construction of unbound granular pavement layers using sub-base or basecourse aggregates.
The sub-base aggregate is usually spread on a prepared subgrade to the specified thickness at the required water content and finally rolled with steel vibrating and static rollers. Commonly, the density requirement is specified as the proportion of that achieved in a laboratory (98% for example).

Laboratories are required to carry out NZS 4402.4.1.3 New Zealand vibrating hammer compaction test to determine the MDD at the OWC of the aggregate used.
Solid density of the aggregate tested is determined according to the NZS 4407.3.7 test method.

It is worth noting, the NZ vibrating hammer test has been having issues with repeatability and reproducibility, namely the test is known to produce inconsistent and variable results.
Recommended literature for a more in-depth understanding of this issue:
NZTA research report 628 - Standardisation of laboratory compaction energies October 2017

Below are visual examples of NZ vibrating hammer and solid density of aggregate particles apparatus.



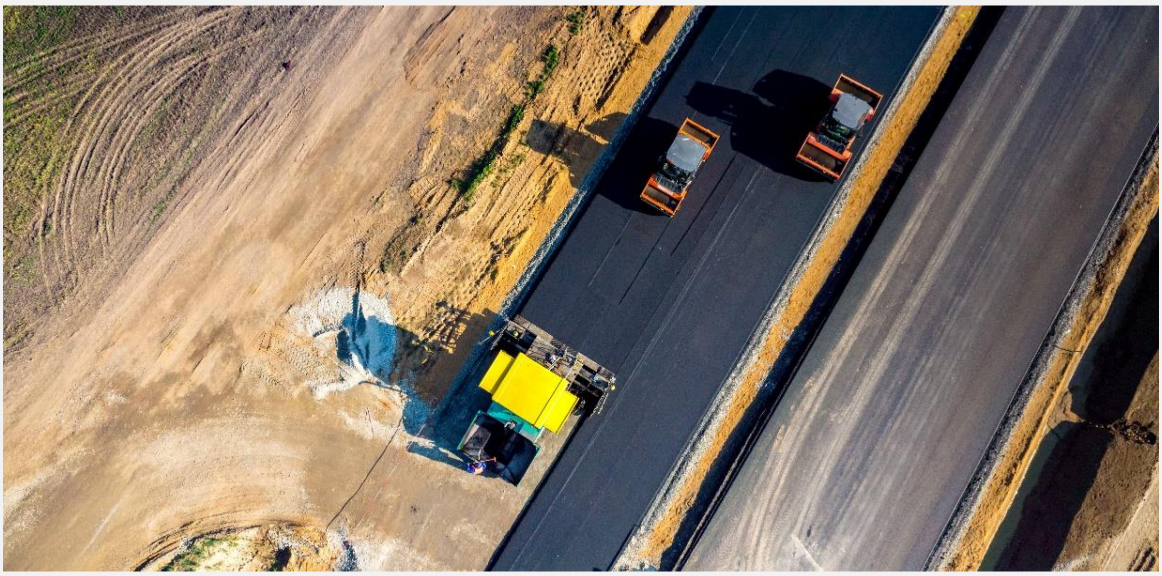

For asphalt, these laboratory tests are commonly used in New Zealand, also as part of NZTA M10 specification:

- AS/NZS 2891.2.2 Compaction of Asphalt Test Specimens Using a Gyratory Compactor
- AASHTO T 312 Standard Method of Test for Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor
- AS/NZS 2891.7.1 Determination of maximum density of asphalt - Water displacement method
- ASTM D2041 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

Below are visual examples of lab equipment for gyratory compaction and “TMSG” apparatus.

Hot mix asphalt is placed at approximately 85 to 92% of the optimum compaction by the paver. The optimum asphalt density is determined in a laboratory before the construction begins. Smooth drum rollers or pneumatic rollers then pass over the freshly placed asphalt, compacting it to the optimum density level. When compacted properly, the mix forms into a long-lasting, solid mat.

Below is a visual example of an asphalt road being paved, then compacted.



Thickness of the layer to be compacted is commonly referred to as lift thickness.
For asphalt it can be from 25mm to 100mm or more, depending on the layer and aggregate size (base, binder, surface), but it is typically far less thick than soil or aggregate layers.

Thin-lift asphalt overlays come in different types, often purpose built for a certain requirement. They can be useful in correcting surface deficiencies, restoring skid resistance, sealing the existing pavement from moisture etc. This type of layer cannot be measured accurately for density with a common NDM designed to take readings of soil, aggregate, concrete, and full depth asphalt at depths between 100 and 300 mm.

Below is a visual example of a thin asphalt overlay being paved and measured.

Recognizing the need for an improved method of measuring the density of thin layer asphalt overlays, Troxler developed the first true thin layer density gauge, the 4640-B Surface Thin Layer Density Gauge, designed to measure the density of thin asphalt and concrete layers from 25 to 100 mm (1 - 4 inches).
In New Zealand it's also referred to as "the thin-lift gauge".

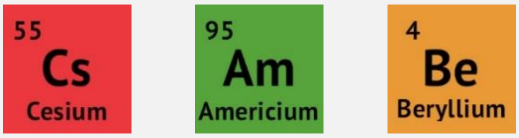
There are other types of compacted material, such as sand and concrete that can also be measured by NDMs. Quality control for all mentioned types of compacted material benefits greatly from the use of NDM as a non-destructive method of accurately measuring the density and moisture.

2. Theory, Operation & Safety

This chapter will cover how nuclear gauges measure density and moisture, and outline safety requirements.

Nuclear gauges use the interaction of radiation with matter to measure density and moisture of materials. Radiation sources within each gauge transmit radiation through the test material. Detectors contained in the gauge measure the radiation that is scattered by the test material or that passes through it.
By measuring the amount of radiation that reaches the detectors, a gauge can determine density or moisture content of the test material.

Caesium, Americium and Beryllium are the most common elements used to make the sources in nuclear gauges. Specific isotopes of these elements are used in making of sources for a particular purpose.



Caesium isotope Cs-137 emits Gamma radiation as it is decaying and is used for density measurements. Americium isotope Am-241 in combination with Be-9 is used to produce neutrons required for moisture measurements.

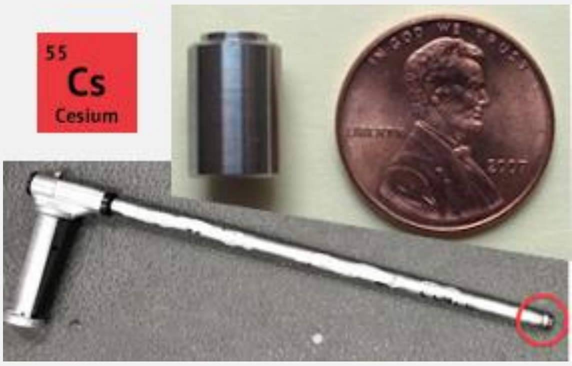
Cs-137 half-life (decaying) duration is 30 years, which is when readings typically deteriorate in accuracy and repeatability beyond practical use. It is recommended to retire and properly dispose of 30-year-old gauges and replace them with newer ones. Please contact us for assistance with NDM disposal.

Radioactivity is measured in units of activity, as opposed to traditional units of mass or volume. Activity represents the number of atoms that decay within a certain period of time. Most common units of activity used internationally are Curie (Ci) and Becquerel (Bq).

Here below are the activities of the two most common sources found in Troxler 3400 series of NDMs:
Caesium 137 0.3 GBq or 8 mCi
Americium 241: Be 1.48 GBq or 40 mCi

These activity values may be familiar to anyone who has had to fill out NDM shipping documents.

NDM sources are fully sealed, double encapsulated in stainless steel. This means that it is very unlikely there will be leakage of radioactive material (contamination), meaning the gauges are very safe to use.
The source itself is quite small, even smaller than a coin.



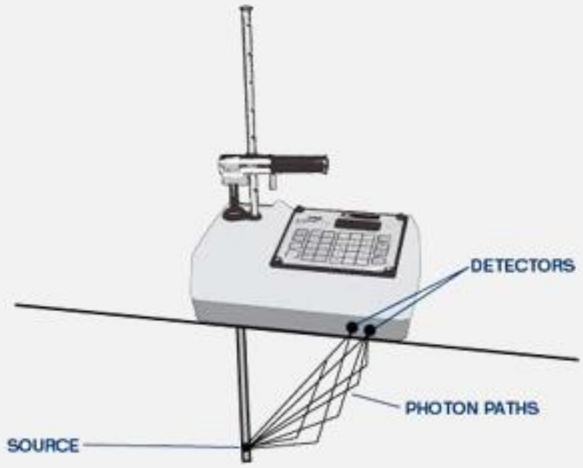
Cs-137 source is located at the tip of the source rod, pushed down by a handle. It can be used at various depth for Backscatter or Direct Transmission density measurement methods.

Am-241: Be source is in a fixed location at the bottom of a gauge and always measures moisture from the surface down.

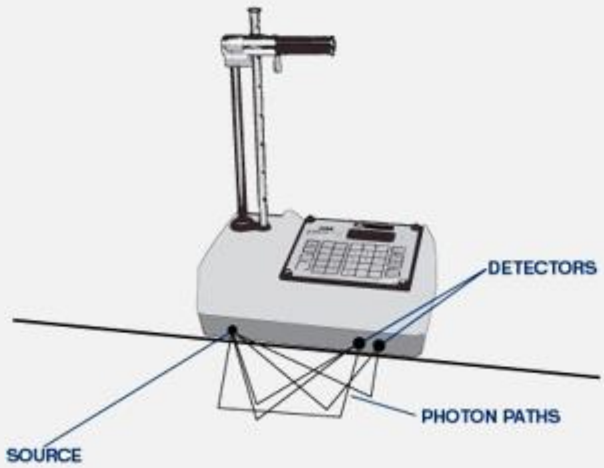
2.1 NDM Density Measurements

Density measurements can be made by two methods with a nuclear gauge: Direct Transmission and Backscatter. The Geiger-Mueller tubes found in a nuclear gauge can detect and measure the amount of direct or scattered gamma radiation that has penetrated through the material being tested.

In Direct Transmission mode, the radioactive source rod extends from the base of the gauge into a pre-drilled hole to a desired depth, as per the picture below.
Gamma photons from the Caesium-137 source pass through the test material to the detectors fixed at the bottom of the gauge. Some photons lose energy along the way. The amount of energy lost is proportional to the density of the test material.
The Direct Transmission mode is used primarily for measuring soil density up to depths of 300 mm.



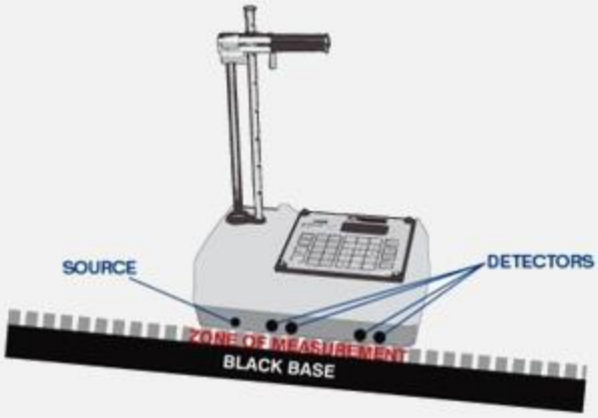
In the Backscatter mode, the radioactive source is lowered to position where it nearly touches but does not penetrate the surface of the test material.
Gamma photons are scattered within the test material. The amount of scattered Gamma radiation that reaches the detectors is related to the density of the material.
The Backscatter mode is useful for measuring asphalt density because no hole needs to be drilled in the test material. However, this mode only measures the density of the top layer of material around 100 mm depth.



There is another measurement mode for use on asphalt, available only on Troxler's 3450 and 4640-B gauges, called Thin Layer mode.

Unlike standard nuclear gauges such as 3430 or 3440, the Thin Layer (or Thin-Lift) gauges have two sets of detector tubes (one set for shallow material and the other set for deeper material) allowing two backscatter measurements at the same time when used in Thin Layer mode. The operator must enter the top layer thickness into the software so the gauge will then be able to calculate the top layer density based on the two measurements.

Thin Layer gauges can measure layer thicknesses from 25 to 100 mm, which makes them highly useful for use on overlay applications, particularly if there are different lifts of asphalt used.



2.2 NDM Moisture Measurements

An NDM can detect moisture as deep as 280 mm, but the major portion of the reading comes from the top 200 mm of the material being tested.

The source used to determine the moisture content of the test material is Americium-241: Beryllium (Am-241: Be). This source emits fast neutrons. Hydrogen (moisture) in the test material will thermalize (slow down) the neutrons coming out from the source. The Helium-3 detectors in the gauge detect the thermalized neutrons. The number of thermalized neutrons is directly proportional to the moisture content of the material.

The moisture source is mounted in the base of the gauge along with the detector tube that reads thermalized neutrons. The moisture is always read directly below the gauge and the depth of measurement depends on the amount of moisture present in the test material.

2.3 NDM Operation

Gauge Warmup

Most Troxler nuclear gauges require a 300-second stabilisation (or warmup) and self-check.
Troxler recommends that all models be turned on 10 minutes before the standard count is taken to allow for the warmup of all systems.

Standard Count

A daily standard count is necessary to regulate the nuclear gauges. This adjusts for source decay and environmental influences such as naturally occurring radiation and hydrogen. A 4-minute daily standard count helps ensure the highest measurement accuracy. The values obtained during this count is used to calculate the density and moisture readings until a new standard count is taken and accepted.

The 3400 series gauges are placed on the polyethylene standard block with the keypad end against the metal butt plate.

The 4640-B gauge is placed on the air gap spacer on the magnesium standard plate.

An appropriate site for the standard count must be chosen:

- The site must be dry and flat
- The site must be at least 3 meters from any large vertical object
- The site must be at least 10 meters from any other radioactive source
- The block must be resting on asphalt, concrete or other compacted material with a minimum density of 1600 kg/m3 that is at least 4 inches (102 mm) thick

The standard counts obtained should be compared to the average of the last four standard counts. The new density count should be within 1% of the average of the last four. The moisture standard count should be within 2% of the average of the last four (for 3400 series gauges).

The daily standard count can also be compared to the reference standard count shown on the most recent gauge calibration report.

Setting Test Parameters

Some parameters will be set up initially and will rarely be changed:

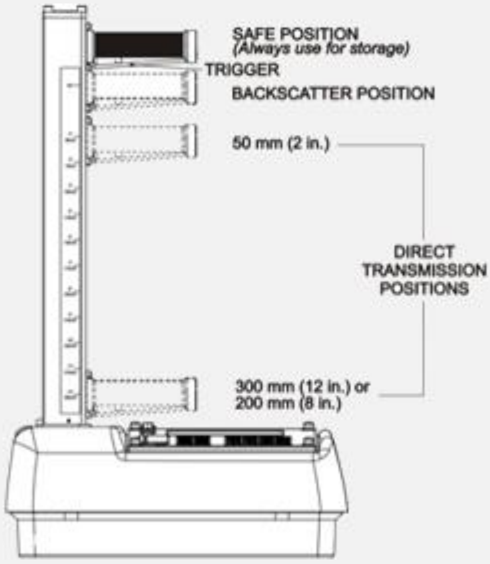
- New Gauge Settings – time, date and company name
- Measurement Units – kg/m3 or pcf
- Depth Mode – Manual or Automatic (Automatic for Models 3440 & 3450)

Some parameters will be changed regularly:

- Test Mode – Soil, Asphalt, or Thin-Layer
- Target – Proctor, Marshall (Gmb), Voidless (Gmm), or Marshall/Voidless pair
- Depth of Test in Direct Transmission – Model 3430 must be set at proper depth manually
- Count Time – 15 seconds, 1 minute, 4 minutes

Preparing to Use

Always make sure the handle is properly seated in a notch before taking a reading. Operator should be able to feel the seating motion and a click of the “slotting in a notch” sound.



For all gauge models it is highly recommended to set the count time to 1 minute for good precision, or 4 minutes for best precision of measurement results. It is not recommended to use the shorter 15 seconds count time due to much lower accuracy.

Below is a visual example of measurement precision statistics for different count times from Troxler.

Direct Transmission (150mm)	**15 sec.**	**1 min.**	**4 min.**
Precision at 2000kg/m³	+/-6.8	+/-3.4	+/-1.7 kg/m³
Composition error at 2000kg/m³	+/-20	+/-20	+/-20kg/m³
Surface error (1.25mm, 100%Void) kg/m³	-17	-17	-17kg/m³
Backscatter (98%) (100mm)	**15 sec.**	**1 min.**	**4 min.**
Precision at 2000kg/m³	+/-16	+/-8	+/-4kg/m³
Composition error at 2000kg/m³	+/-40	+/-40	+/-40kg/m³
Surface error (1.25mm, 100%Void) kg/m³	-75	-75	-75kg/m³
Moisture	**15 sec.**	**1 min.**	**4 min.**
Precision at 250kg/m³	+/-10.3	+/-5.1	+/-2.5kg/m³
Surface error (1.25mm, 100%Void) kg/m³	-18	-18	-18kg/m³
Depth of measurement at 250kg/m³ = 212.5mm			

Offsets

Offsets may be necessary for a particular situation. The offset must be disabled or changed if the applicable conditions change or do not apply.

Offsets will be necessary for testing materials that:

- have a wet density outside of the range 1450 to 2700 kg/m3
- contain hydrogen-rich material
- are inside of a trench or close to a building

Trench Offset – This offset compensates for the influence of vertical structures on measurements. Use a trench offset if taking measurements inside a trench or within 0.6 meters (2 feet) of a large vertical structure. The walls of the trench or structure often "echo" gamma photons and neutrons, adversely affecting density and moisture measurements.

Moisture Offset – A negative moisture offset is needed when testing certain materials that contain high amounts of hydrogen rich compounds. Some of these include: cement, gypsum, coal, lime, fly ash, organic materials, mica and phosphates. Less commonly, some materials contain neutron absorbers and will require a positive moisture offset. Boron and cadmium are examples of neutron absorbers. This offset is determined by performing an oven dry moisture analysis.

Density Offset – A density offset may be necessary if the material being tested is outside of the calibrated density range or if the material is composed of materials such as industrial waste, mine tailings, or similar material having a chemical composition which is different than the normal range of soils. In asphalt density testing this may be necessary to adjust the gauge readings due to large aggregates, high air voids, or RAP materials present in the mix. The correction factor is determined by comparing the gauge readings to the results of an alternative density test (core sample, sand cone test, etc.). The correction factor is applied as a plus or minus offset to the measured wet density.

Superpave Asphalt Mixes - Superpave asphalt mixes attempt to eliminate permanent deformation of asphalt pavements and low temperature cracking, with a design goal of achieving a strong stone skeleton that will resist rutting yet include enough asphalt and voids to improve the durability of the mix.

Gyratory Compactor fabricates a test specimen that allows the:

- Determination of volumetric properties of the asphalt
- Verification that the delivered asphalt mix meets the job volumetric specifications
- Specimen to be much more representative of actual in-service pavements

Nuclear Density Gauges and Superpave:

- An offset or special calibration should be performed; do this on the test strip when beginning the placement of a mix
- Core analysis should be performed with a paraffin or parafilm coating if aggregates are coarse

Plateau Testing

The calculation of the number of passes for compactors and lift thickness of material being compacted is critical to attain the required degree of compaction. The only practical way of determining optimum compaction in the field is with an NDM. The lift thickness generally varies, for example between 150-300 mm based on soil type, and most of the compaction is achieved through the first five passes.

Maintaining optimum moisture content is critical for achieving maximum dry density. Nuclear density gauges can be used for measuring moisture content of stockpiles as well as compacted material.

Strip test is a common test method that enables engineers to specify the number of passes and compactor type.

The number of passes required to obtain the required compaction depends on the lift thickness, moisture content and contact pressure. Energy returns to the compactor as the material gets compacted. The returned energy intensifies as the compaction degree increases and an experienced driver can tell by feel when optimum compaction has been achieved. Modern compactors are equipped with intelligent systems able to automatically control compaction force and sense when set compaction target is achieved.

Useful tips and advice for NDM operators taking readings in the field:

- Make sure proper NDM and site preparation steps are undertaken, as per the NDM user manual


- Tap the handle to make sure the source rod is seated in the appropriate notch relating to the required measurement depth
- If possible, always use air dried and sieved native fines to fill in the voids on the surface of NDM measurement spot on the ground
- Air dried crusher dust 2-3 mm size seems to work well as an alternative filler, for example
- It's recommended to avoid using single size industrial sand as filler, it tends to get statically charged and cause issues with rod seating on the following reading attempts and thus consistency of readings
- When performing a direct transmission reading, remember to push the gauge forward or to the right when facing the keypad. This closes the small gap between the source rod and the material to be measured


- Achieving 100% compaction in the field is rare
- Healthy operator experience on using NDMs has historically proven to provide reliable measurement readings, it's recommended that new users should seek guidance of more experienced operators in addition to attending training courses

2.4 NDM Safety

To be allowed to own and/or use an NDM, there are codes of practice and safety plans to be followed to ensure everyone's safety and proper use of the equipment. The Ministry of Health's Office of Radiation Safety (ORS) administers the Radiation Safety Act 2016 and the Radiation Safety Regulations 2016 on behalf of the New Zealand Government.

The scope of information can be overwhelming to take in all at once, and often questions about proper use and safety are intertwined.

Groundtest Equipment regularly offers training courses for operators of nuclear moisture/density gauges.
The one-day training courses are held throughout the year in Auckland, Wellington, and Christchurch, and sometimes in other regional centres or for in-house training. These courses are recognised by the Office of Radiation Safety as sufficient "core of knowledge" safety training before applying for a use license.
Training courses are a highly recommended source of information on the nature of radiation, just how much of it comes from a nuclear gauge and how to best protect yourself, your co-workers and other people in your proximity.
The last part of the training course covers NDM operation, use and maintenance.

In 2020 Ministry of Health has released an updated C12 Code of Practice for Sealed Radioactive Material.
This is of relevance to all existing and future owners and users of Nuclear Density Meters.
Further explanation is available on ORS Codes of Practice page, one of new additions as follows:
"*What measurements are required for workplace monitoring?*
C12 requires managing entities to establish a programme of workplace monitoring, which for NDMs are confirmatory radiation measurements that are done with a survey meter."

A survey meter is a useful tool for measuring radiation outside of the nuclear gauge. A survey meter can be used to evaluate the radiation levels of storage areas and work sites. Survey meters help ensure a safe working environment. The Monitor 200 survey meter is approved for use in New Zealand.

3. NDM Costs

Once a suitable Troxler NDM has been selected, it is a good time to enquire on costs of a survey meter, indoor safety signs and labels and vehicle mounted signs, leak test kit, DG documents and safety training for each user. It is also recommended to review other associated costs of owning a nuclear gauge, as below.

A source licence is obtained via application form found on ORS webpage Source licences for non-medical and veterinary purposes.

For the use of radiation for non-medical purposes a use licence must be obtained via application form found on ORS webpage Users of radiation.

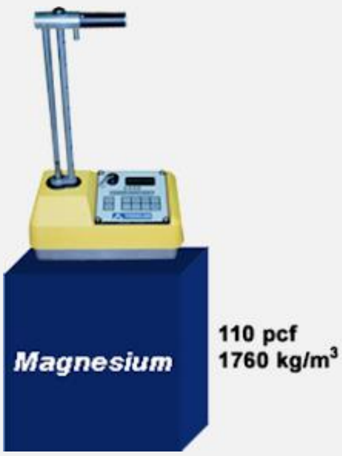
Registering a NDM is easily done via ORS webpage Register radiation sources, and is free of charge. Owners are required to notify ORS of new NDM arriving at their facility to complete the registration process. This will update the status of the above-said registration entries from “pending arrival” to “in use”.

As part of the safety plan, NDM users will need to allow for appropriate lockable storage space at their office or laboratory. A vehicle with suitable space and safety measures may be required as well.
Individual dosimeters are required to monitor radiation exposure of NDM operators.

And lastly, there will be a bi-annual cost of IANZ calibration for each NDM, frequency recommended by Troxler. Calibration becomes necessary because the wear in the bearings and ageing of electronics affect the accuracy of the gauge readings.

We apply the most advanced method of calibration available today – developed by Troxler.

An in-depth service (and repairs if required) are done at the same time, which greatly extends life of a gauge. Groundtest calibration lab offers a booking system which in return provides a quick turnaround.



There may be other associated costs that are circumstance dependent and not covered by this guide.

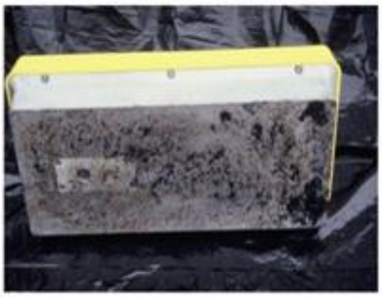
4. NDM Maintenance

Here below are some of the steps we recommend all NDM users to be aware of.

- Change batteries as needed.
- Perform a leak test on each NDM every 2 years.
- Regularly clean and lubricate the shutter mechanism.

- Keep water (rain) away from NDM, best method: avoid using it while it rains.
- Keep the inside of the case clean and dry.

- If the overlay on the keypad is peeling or difficult to read, clean or replace as needed.
- If condensation forms inside the gauge or when taking the gauge from hot-to-cold or cold-to-hot environments, prop open the keypad control panel and allow for temperature to equalise. If necessary, use a hair dryer (on low setting) to blow air into the base of gauge for a few seconds at a time.
- Lubricate the source rod lightly with Magnalube.
- Clean the gauge base to remove any asphalt or soil that may be stuck to it. Foreign material stuck on the base will cause air voids under the gauge, lowering the density reading significantly.




Here are some useful quick links:

- You can find information on [how to ship a nuclear gauge] in New Zealand.
- You can find answers to many [frequently asked questions] about common problems.
- You can [download manuals] for most Troxler gauges.

5. NDM Test Standards

New Zealand standards:

- NZS 4407.4.2:2015
  The field water content and field dry density of compacted materials - method using a nuclear moisture-density gauge - direct transmission

- NZS 4407.4.3:2015
  The field water content and field dry density of compacted materials - method using a nuclear moisture-density gauge - backscatter mode

- AS/NZS 2891.14.2:2013
  Methods of sampling and testing asphalt - Field density tests - Determination of field density of compacted asphalt using a nuclear thin-layer density gauge

International standards:

- ASTM D6938 - 17a
  Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

- AASHTO T 310 - 13
  Method of Test for In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

- ASTM D2950 / D2950M - 14
  Standard Test Method for Density of Bituminous Concrete in Place by Nuclear Methods

- AASHTO T 355 - 18
  Standard Method of Test for In-Place Density of Asphalt Mixtures by Nuclear Methods

- ASTM C1040 / C1040M - 16a
  Standard Test Methods for In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods