Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Working Safely With Nuclear Gauges

Canada

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INFO-9999-4 (E) Revision 2
Published by the Canadian Nuclear Safety Commission

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Canadian Nuclear Safety Commission
280 Slater St.
P.O. Box 1046, Station B
Ottawa, ON K1P 5S9
CANADA

Telephone: (613) 995-5894 or 1-800-668-5284 (Canada only)
Fax: (613) 995-5086
E-mail: info@cnsc-ccsn.gc.ca
Web site: www.nuclearsafety.gc.ca

Le présent livret est également disponible en français.

Cat. No. CC172-6/2007E-PDF
ISBN 978-0-662-44169-4

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Introduction

This booklet contains guidelines on the safe handling and use of fixed and portable nuclear gauges, and provides background information about radiation for people who work with or near these gauges.

You may be uncertain about the possible dangers from working near gauges that contain a radioactive source, but used properly these tools pose no hazard to your health. This booklet should be used in conjunction with the operating manual for your particular nuclear gauge. After reading both, you should be able to work confidently and safely with or near nuclear gauges.

Remember that this booklet is meant only as a general guide and is not intended to be the sole method of training. Specific information and requirements may be found in the manufacturer's operating manual, your Nuclear Substances and Radiation Devices licence issued by the Canadian Nuclear Safety Commission (CNSC), as well as the *Nuclear Safety and Control Act* (NSCA) and applicable regulations. If you are uncertain of any terms, please check the glossary at the back of this booklet.

The Canadian Nuclear Safety Commission

The CNSC is best described as the nuclear energy and materials watchdog in Canada. The CNSC is a federal agency responsible for regulating the nuclear industry in Canada through the implementation of its regulatory framework. It applies and enforces regulations under the *Nuclear Safety Control Act.*

As the regulator, the CNSC issues licences and continually monitors licensees to ensure they comply with safety requirements that protect workers, the public, and the environment, and uphold Canada's international commitments on the peaceful use of nuclear energy. All nuclear gauges used in Canada must be certified by the CNSC to ensure that they are safe to use for the intended application. For more information, or to contact the CNSC, please use the contact information on the publication details page at the front of this booklet.

What is Radiation?

In order to understand nuclear gauges, you must first understand some basic facts about radiation, its origins, and its possible effects.

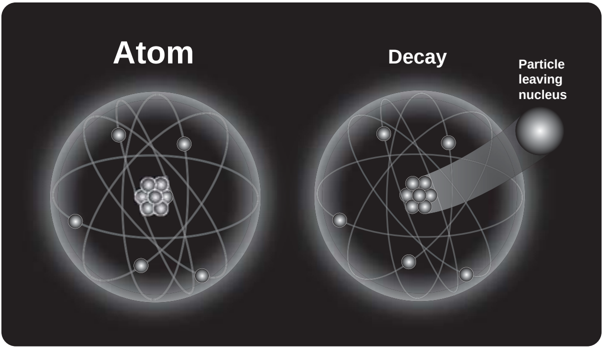
Radiation, in the broadest sense, simply means energy given off by any object, such as heat energy from a fire. What we are concerned with more specifically is *ionizing radiation*. This describes particles or waves with enough energy to ionize the material they pass through (by removing electrons from atoms). While ionizing radiation can be potentially harmful, it's important to remember that we are exposed to it at some level at all times. In fact, natural background radiation — from soil and rocks, from the food we eat, from the air we breathe, from the houses we live in, from cosmic rays, even from our own bodies — contributes to about three quarters of our annual radiation exposure. The rest of our exposure comes from a variety of artificial sources of radiation. Medical diagnostic procedures such as x-rays and nuclear medicine scans make up the vast majority of most people's exposure to artificial sources of radiation. The combined amount of exposure to both natural and artificial sources of radiation each year by the average Canadian is so low that it presents no significant health risk.

The concept of radiation 'dose' is used to quantify the amount of radiation to which a person is exposed. Doses are measured in sieverts. The sievert (Sv) is the accepted international unit for measuring the amount of radiation absorbed by the body, and is often expressed in milliSieverts (mSv), or microSieverts (µSv) (1 mSv = 1000 µSv). Exposure to natural and man-made ionizing radiation varies slightly across Canada, but the average radiation dose is about 2.7 mSv per year. Most of this — about 2 mSv — comes from naturally occurring sources.

How ionizing radiation occurs

Most ionizing radiation occurs when the structure of an atom breaks down and energy is released (see Figure 1) as a wave or particle. This can happen from an atomic collision or when an unstable atom (called a radioisotope) decays or breaks down on its own. Radioisotope samples continually release radiation until all of their atoms have become stable. Such radioactive materials are used in nuclear gauges. Each radioisotope has a predictable rate of radioactive decay, and the radiation produced has a characteristic "penetrating power".

Figure 1



When an atom's structure breaks down, as shown here by a particle leaving the atom's nucleus, energy is released as ionizing radiation. This radioactive decay continues until the atom changes to a stable form.

Radiation from alpha particles to x-rays

Here are the main types of ionizing radiation:

- **Alpha radiation:** Large atomic particles, usually emitted with a high energy. Alpha particles have very little penetrating power. Consequently, radionuclides that emit alpha particles are not an external exposure hazard but can be harmful if the material is inhaled or ingested. Alpha radiation can be emitted from both natural elements and artificial substances.

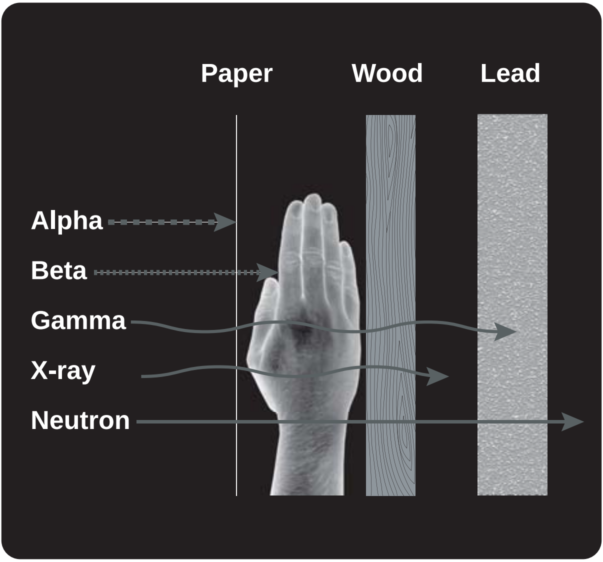
- **Beta radiation:** Electrons or positrons with penetrating power varying with the energy of the particle. They present an internal exposure hazard and higher-energy beta particles may also be an external exposure hazard. Beta emitters are frequently found in medical or research environments.

- **Gamma radiation:** Electromagnetic waves with a range of energies, originating from the nucleus of an unstable atom. As the waves ionize atoms they pass through, they become progressively less able to penetrate matter and are reduced in number (or attenuated). They may present a serious external exposure hazard, often having greater penetrating power than medical x-rays. Shielding such as steel or lead provides effective attenuation. **Gamma emitters are often found in devices such as fixed and portable gauges.**

- **Neutron radiation:** Uncharged particles emitted from the nucleus of certain elements, and which may also be artificially produced. When a neutron collides with an atom of a molecule, the atom absorbs a portion of the neutron's energy.The hydrogen atom is capable of causing the greatest reduction in energy, so hydrogenous material such as water and wax make the best neutron shields. Once the neutron has lost most of its energy, it can be captured by an atom and this newly formed atom may give off a high energy gamma ray. **Neutron radiation is often used in portable nuclear gauges.**

- **X-rays:** Machine-generated electromagnetic waves which are otherwise physically identical to gamma radiation. This type of radiation is used primarily in medical applications, but is also used in some industrial environments.

Figure 2



The various types of ionizing radiation have different penetrating powers. This illustration portrays the ability of different forms of ionizing radiation to penetrate paper, the human body, wood and lead.

Using Radiation Safely

All types of ionizing radiation can be harmful. Long-term exposure to a small source of constant radiation, or short-term exposure to a large amount of radiation, can cause damage to the cellular structure of body tissue or organs. However, these risks can be minimized and controlled, allowing radioactive sources to be used safely for many productive purposes.

Nuclear Gauges

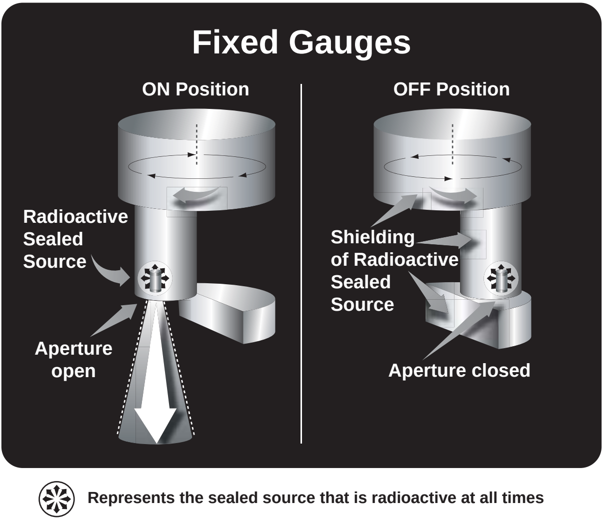
Today, many industries use nuclear measuring gauges that incorporate a sealed source containing a radioactive nuclear substance. Because we know the penetrating power of the radiation emitted by specific substances, nuclear gauges provide an inexpensive, yet highly reliable and accurate method of measuring the thickness, density or make-up of a wide variety of materials or surfaces. There are two types of nuclear gauges: fixed and portable.

Fixed gauges

Fixed gauges (see Figures 3 and 4) are most often used in mines, mills and production facilities as a way of monitoring a production process and ensuring quality control.

In many processes, either the products cannot be effectively checked by traditional methods that require direct contact, or a non-destructive measuring technique is desired. In these situations, a fixed nuclear gauge can be used to provide precise measurements of thickness, density or quantity. These fixed gauges house a sealed source that contains a radioactive nuclear substance. When the source holder's shutter is opened, an invisible beam of radiation is directed at the material being processed. A detector, mounted opposite the sealed source, measures the radiation that passes through the material. A read out, either on the gauge or on a connected computer terminal, registers the required information. For example, in a paper mill, fixed gauges can measure the thickness of a sheet of paper as it leaves the presses, while in a brewery, a fixed gauge makes sure that each bottle contains the right amount of beer. Whatever the application, these gauges ensure quality control in a process. The passage of radiation through the material does not cause any physical or chemical change, and the material itself does not become radioactive.

Figure 3



Fixed gauges are widely used today in factories and processing environments to ensure quality control. Opening the shutter allows the radiation to pass through the material and to be measured by a detector mounted opposite the source, as shown in Fig. 3. The amount of radiation detected indicates the thickness or density of the material. The shutter may be opened manually (by a lever or switch) or electronically.

Figure 4

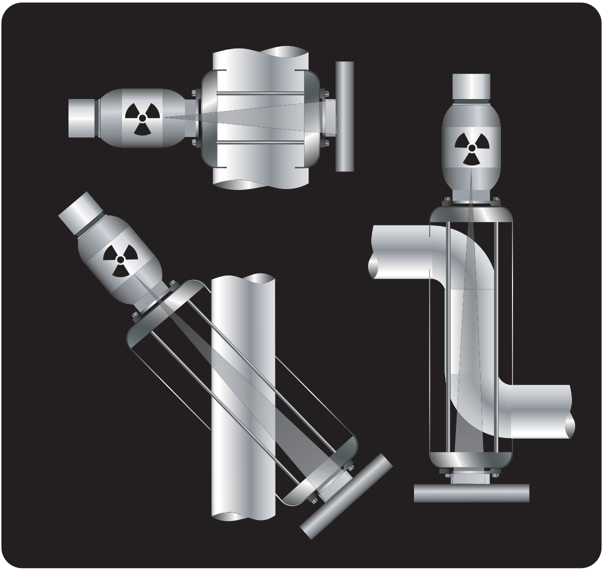


Fig. 4 shows different configurations for fixed gauges attached to pipes.

Portable gauges

Portable gauges (see Figures 5 and 6) are used in industries such as agriculture, construction, and civil engineering to measure things like the moisture or compaction in soil, and the density of asphalt in paving mix.

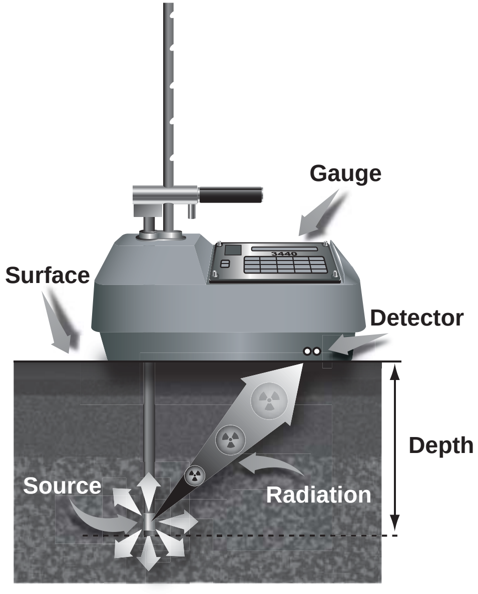
There are two basic methods of measuring material with portable gauges; the backscatter method, and direct transmission method.

"Direct transmission" is considered the more precise of the two, as it produces less error in measuring composition and compensates for surface roughness. To measure soil density, for example, the source rod is placed in a tube and inserted beneath the surface through a punched access hole. Radiation is then transmitted from the source to a detector on the base of a gauge. The compaction of the soil is determined by the radiation level at the detector.

The "backscatter method" eliminates the need for an access hole by allowing both the source and detector to remain on the surface. Radiation is directed beneath the surface, where some radiation is reflected, or "scattered", back to the gauge detector by the surface material. This method can be used either to measure the moisture content of the material using a neutron source, or to measure material density using a gamma source. When used for density measurements, it is less accurate than direct transmission due to the large scattering angle and shallow depth of measurement. It is also insensitive to density variations beyond a depth of 5 to 7.5 cm (2 to 3 inches). However, the backscatter method is quicker and easier than direct transmission, and is useful when measuring uniform material such as asphalt paving.

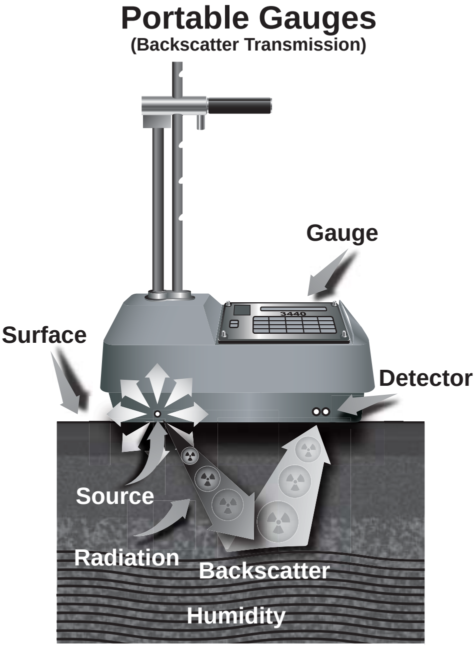
Figure 5

Portable Gauges
(Direct Transmission)



The use of portable gauges is widespread in industries such as agriculture and construction. In Fig. 5, the gamma source is placed underneath the surface of the ground through a tube. Radiation is then transmitted directly to the detector on the bottom of the gauge, allowing accurate measurements of compaction.

Figure 6

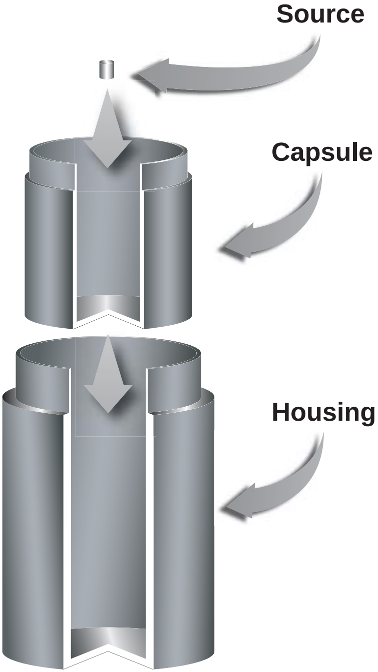


In Fig. 6, the neutron source remains above the surface, and radiation is emitted into the ground and scattered back to the detector to provide a measurement of the moisture content or density of a material.

The strength of the source

Each nuclear gauge uses one or two small radioactive sources such as cesium 137, americium 241/beryllium, radium 226 or cobalt 60. The source's strength is measured in terms of how much radiation it emits. Although these sources are physically quite small, they are often extremely powerful and highly radioactive. However, it is the amount of radiation you absorb, not the strength of the source, that can pose a danger to your health. The amount of radiation absorbed is controlled by the source shielding and by proper handling techniques.

Figure 7



Capsule and housing caps not shown

All nuclear gauges use a radioactive source that is placed in a special multi-layered capsule. This capsule, which can be as small as the eraser on the tip of a pencil or as large as the tube inside a roll of paper towels, is then inserted into the gauge's source housing, which shields the radiation emitted from the source.

Are Nuclear Gauges Safe?

Nuclear gauges are as safe as using a power saw or a welding torch. As with those tools, safety precautions must be taken. However, since the potential harm from radiation is not as obvious as the danger from a sharp blade or a flame, the safety precautions are not obvious either. By following a few simple rules, you can be assured that working with or around nuclear gauges will pose no threat to your health and safety.

Principles of radiation protection

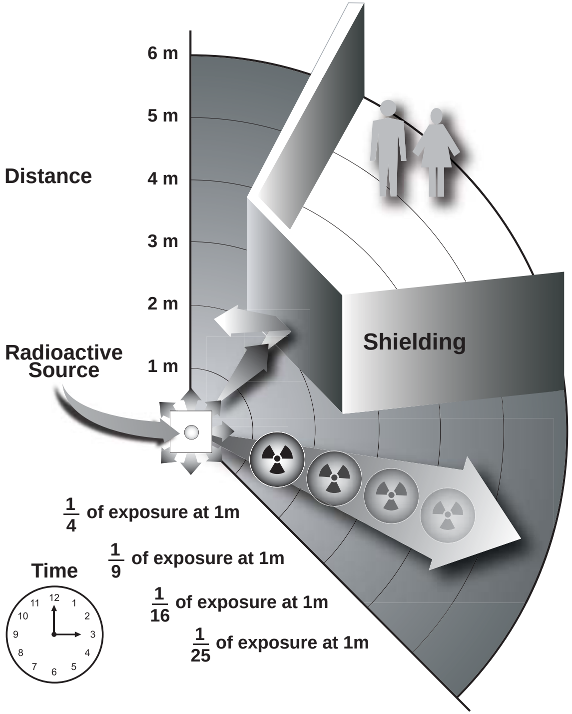
Three factors (see Figure 8) come into play when protecting yourself from the effects of radiation:

- **Time:** The less time a person remains in the area of radiation, the lower the radiation dose that person will receive. Work should be carried out quickly and efficiently, but with attention to safety.

- **Distance:** The intensity of radiation and its effects fall off sharply as you move further away from the radioactive source. The dose rate decreases as the inverse square of the distance from the source. For example, by moving twice as far away from a radioactive source, you are exposed to one-quarter the amount of radiation; moving three times as far away means one-ninth the exposure, and so on (see Figure 8 for illustrated examples).

- **Shielding:** Protective material placed between you and the source reduces the level of radiation to which you are exposed. The source, in its capsule, is inserted into the gauge's source housing, which shields the radiation emitted from the source (see Figure 7).

Figure 8



The three elements of radiation protection are ***time***, ***distance*** *and* ***shielding***. *The shorter the time spent close to the source, the lower the radiation dose that will be received. Likewise, the effects of radiation fall off sharply the further you move away from the radioactive source. The thicker the protective material placed between you and the source, the less the amount of radiation to which you will be exposed.*

Keeping Doses ALARA and Worker Designation

Licensed users of nuclear gauges must ensure that doses are kept 'as low as reasonably achievable' (ALARA). The CNSC facilitates this by regulating the use of radiation devices, by assessing radiation protection programs, and by regularly inspecting licensees to ensure compliance with the regulations and licence conditions. The CNSC also sets limits on the amount of radiation to which you may be exposed, depending on your job.

Any worker who is required to perform duties with a reasonable probability of receiving a radiation dose greater than 1 mSv per year must be designated as a Nuclear Energy Worker (NEW). The regulatory dose limits for NEWs are 50 mSv per year and 100 mSv over a five year period.

Portable gauge workers may or may not have to be designated as NEWS, depending on the number of measurements performed by each individual worker. In general, workers who perform more than 800 measurements each year should be designated as NEWS, since previous studies indicate that each measurement typically results in a 1.0 to 1.2 μSv dose to the worker.

If a worker is designated as a NEW, the licensee must inform him or her of that status, of the risks associated with the radiation to which they may be exposed, of the regulatory dose limits, and of the dose they receive as a result of their work. All female NEWs must be informed of their rights and obligations should they become pregnant. The licensee must obtain written confirmation that the NEW has been informed of all of the above.

In general, persons working around fixed gauges receive almost no radiation dose, and thus do not need to be designated as NEWs.

A list of authorized workers and their NEW status, if applicable, must be maintained by the licensee.

Keeping track of your radiation dose

There are two common methods of determining the radiation doses received by persons working with nuclear gauges.

Portable gauge users may estimate their total dose based on the number of measurements performed in a year. Using the number of measurements performed in a year multiplied by an estimate of the dose received per measurement can give an estimate for the total radiation dose received. Dose estimates can be done for fixed gauge users as well by multiplying the hours of work in proximity to the gauge by the dose rate in their work area.

Alternatively, the licensee may choose to monitor their workers using a personal measuring device called a “dosimeter”. The most commonly used type of dosimeter for gauge users is the thermoluminescent dosimeter, or “TLD”. Due to the small amount of radiation received by most workers, TLDs are not normally required and their use is usually optional. However, if there is a reasonable probability of receiving a dose greater than 5 mSv in a one-year period, you are **required** to wear a TLD.

TLDs contain small chips of material that absorb radiation in a measurable form. They should be worn between the waist and neck area. They should not be exposed to high temperature or water, or left in direct sunlight. When not being worn, they should be stored in a low radiation area away from the gauges. TLDs are read by agencies licensed by the CNSC. Any dose that exceeds the limits in the CNSC *Radiation Protection Regulations* must be reported to the CNSC.

Figure 9

The dosimeter badges shown here measure your accumulated dosage. On the left is an electronic dosimeter, which gives a direct reading. On the right is a thermoluminescent dosimeter (TLD) which is generally read every three months.

Certification, licensing, inspection and testing

All gauges must be certified by the CNSC and approved for use in Canada before being put into operation. Once a gauge is certified, and the applicant has the proper procedures in place, the CNSC issues a licence to the company who will be using it.

Gauges must be checked regularly to ensure that the source is secure within its capsule and that there is no leakage. Every 12 months, the licensee must arrange for a CNSC-approved organization to perform these leak tests. The licensee will receive a leak test certificate showing the results. Any device that is found to have a leaking source must be removed from use and the CNSC must be notified immediately.

A small amount of radiation always penetrates the gauge housing and can be detected using a sufficiently sensitive radiation detector even if the source capsule is intact. This low level radiation poses no significant health risk.

Conditions on your licence further control the use and handling of the gauges.

To ensure that licence conditions and CNSC Regulations are being followed, the CNSC may perform both Type I inspections (audits) or Type II (compliance) inspections. These inspections are also used to confirm that the licensee is implementing an effective radiation protection program consistent with regulatory requirements.

In order to ensure complete safety with nuclear gauges, you must, as with any type of equipment, follow the operating instructions. Additional radiation safety training should be done for all workers using the radiation devices. This should include basic radiation safety, information about the specific nuclear substances involved, methods of keeping doses ALARA, review of the licence and its conditions, and review of the *Nuclear Safety and Control Act* and the pertinent regulations. Specific transportation training should be done and Transportation of Dangerous Goods (TDG) training certificates issued if required. Radiation safety awareness training should be provided to workers who are not necessarily gauge users but who may work in the proximity of nuclear gauges. It is recommended that refresher training be done every 3 to 5 years.

The following section provides guidelines on the proper use of nuclear gauges while specific instructions are available in the manufacturer's operating manual.

Proper Use of Nuclear Gauges

The CNSC requires that all nuclear gauge users have some form of radiation safety and awareness training. Always carefully follow the operating procedures provided by the manufacturer. If the manufacturer's instructions differ from the CNSC's requirements, you must comply with CNSC Regulations.

The following is a set of general guidelines on using, maintaining and servicing, storing, transporting, and disposing of fixed and portable nuclear gauges.

Guidelines	Fixed	Portable
Before you start		
Never use or manipulate a gauge without proper training and authorization.	✓	✓
Read and understand the conditions of the licence, the operator's manual, the applicable sections of the CNSC Act and Regulations and the internal radiation safety policies and procedures.	✓	✓
Post a copy of the licence in a common area where all workers can see it.	✓	✓
Keep a copy of the licence with the gauge.		✓

Continued on the next page

Guidelines	Fixed	Portable
Ensure that radiation warning signs and 24-hour emergency contact details are prominently posted in each area of use or storage.	✓	✓
Advise other workers that a gauge is being used.		✓
Maintenance and service		
Only the manufacturer of the gauge or another person licensed by the CNSC to service gauges should attempt to repair the source, source holder or shutter.	✓	✓
Always ensure shutter is closed until maintenance is completed.	✓	✓
Avoid any physical contact with, or direct exposure, to the source when performing any maintenance.	✓	✓
If necessary, clean the area around the shutter to prevent dirt build up.	✓	✓
Make sure the gauge is leak-tested every 12 months.	✓	✓

Continued on the next page

Guidelines	Fixed	Portable
Mounting/dismounting and vessel entry procedures must be approved by the CNSC. Authorization for these activities is given in a licence condition.	✓	
A calibrated survey meter is required to verify that the nuclear gauge is in a shielded position prior to mounting/dismounting the nuclear gauge or accessing a vessel.	✓	
Storage		
Before storing the gauge, make sure the source is in the "Safe" position.	✓	✓
Lock the source and shutter in place.	✓	✓
Never modify or change the source holder, shielding or safety interlocks.	✓	✓
Store the gauge in a locked, fire-resistant container (such as a Type A labelled transport case).	✓	✓
Identify the container in case the gauge is lost, damaged or misplaced.	✓	✓

Continued on the next page

Guidelines	Fixed	Portable
Lock the area where the gauge is being stored.	✓	✓
Post a radiation warning sign and 24-hour emergency contact details outside the storage area.	✓	✓
If a storage location is to be used for more than 90 days, the CNSC should be informed in writing (the gauge may be temporarily moved in and out of the location during this time).		✓
Transportation and transfers		
Prior to transferring a gauge, you must ensure that the recipient has a valid and appropriate licence for the gauge.	✓	✓
When taking a gauge to and from a job site, place it in its storage container and keep it in an unoccupied part of the vehicle, such as the trunk. Always lock the vehicle if the gauge is inside and unattended by an authorized worker. If carrying on the bed of a pickup truck, ensure it is not left unattended unless the gauge is physically attached to the vehicle by a locked chain, cable or other means, so that it cannot be removed by an unautorized person.		✓

Continued on the next page

Guidelines	Fixed	Portable
All requirements in Transport Canada's *Transportation of Dangerous Good Regulations* and in the CNSC *Packaging and Transport of Nuclear Substance Regulations* must be met. All workers who offer for transport and/or transport a gauge must be trained and have a valid Transportation of Dangerous Goods (TDG) certificate.	✓	✓
Gauges may be transferred back to the supplier, to another licensee or to a waste disposal organization licensed by the CNSC. The inventory should be adjusted accordingly to reflect any transfers.	✓	✓

Emergency Procedures

Your company or organization must have a set of emergency procedures and a plan of action in case of an accident or in the event of damage to the gauge. In general, the following steps should be followed:

For fixed gauges

- Cease work immediately.
- Notify the Radiation Safety Officer.
- If the gauge has been partially damaged or destroyed, keep people at least 5 m (approximately 16 ft) away until the source is replaced, reinstalled, or shielded, or until radiation levels are known to be safe.
- Have leak test performed after any incident that may result in source damage.
- In case of an accident or fire, do not use the gauge until the damage is assessed by a qualified person.
- Inform the CNSC as soon as practical of any theft, accident or incident.
- A full written report must be submitted to the CNSC within 21 days of a loss or accident.

For portable gauges

- Cease work immediately.
- Keep people at least 2 m (approximately 6 ft) away until the source is removed or until radiation levels are known to be safe.
- Inform the Radiation Safety Officer.
- If the damage is minor or superficial, and the source is in the safe, shielded position, a Type A transport

container (such as the gauge transport case) can be used to transport the device if radiation levels do not exceed the transport index (TI) for your gauge (TI levels are given in the device or shipping documentation). Type A containers are labelled as such. If you do not have a radiation survey meter, do not move a damaged gauge until its radiation level is checked.

- If the damage is severe or the source rod will not retract, a special transport container such as a steel drum with a secure lid and sand or gravel as shielding may be used. (The CNSC must be contacted. Special precautions, packaging and permission may be necessary in order to transport the damaged gauge.) A calibrated survey meter must be used to ensure safe radiation levels.
- Before the site is re-opened for regular use, a calibrated radiation survey meter must be used to verify that all sources have been retrieved. If the licensee does not own a meter, arrangements must be made with an external company to ensure that a meter is available in case of accident.
- In case of an accident or fire, do not use the gauge until the damage is assessed. A leak test must be performed after any incident that may have resulted in source damage.
- Inform the CNSC as soon as practical of any theft, accident or incident.
- A full written report must be submitted to the CNSC within 21 days of a loss or accident.

Nuclear gauges present no major health dangers if basic precautions are taken and common sense used. By following proper procedures and the principles of radiation protection, and by helping others do likewise, you can feel comfortable and assured that your workplace is a safe one.

Glossary of Terms

artificial radiation: the radioactive substances, or sources of radiation, created by human intervention, e.g., a medical X-ray

background radiation: naturally occurring radiation to which we are exposed all of the time

Canadian Nuclear Safety Commission (CNSC): the federal regulatory body responsible for ensuring the safety and security of nuclear products and facilities

compliance inspection: an inspection conducted by the CNSC to ensure that leak tests have been performed on schedule, and that licence conditions and the CNSC regulations are being followed

dose: the radiation absorbed by the body

dosimeter: a personal measuring device used to monitor the amount of radiation absorbed by a person

external exposure: radiation exposure due to proximity to a radioactive source

internal exposure: radiation exposure from radioactive dust or gases inside the body (from ingestion, inhalation or absorption through skin)

ionizing radiation: radiation which may ionize atoms through which it passes (removing electrons), and is potentially dangerous to humans

leak tests: annual tests performed on nuclear gauges to ensure that the source capsule is intact

radioisotope: a radioactive element or form of element, either artificially-occurring or naturally-occurring

rem: the old unit for measuring a radiation dose; 1 rem = 0.01 sievert

sealed source: a radioactive element encased in a protective capsule and used in equipment such as fixed or portable nuclear gauges

sievert: the metric unit for measuring a radiation dose; 1 sievert = 100 rem

CNSC Relevant Documentation:

Nuclear Safety and Control Act
General Nuclear Safety and Control Regulations
Radiation Protection Regulations
Nuclear Substances and Radiation Devices Regulations
Packaging and Transport of Nuclear Substances Regulations
INFO-0483—Responding to Accidents Involving Portable Gauges
INFO-0742—Proper Care and Use of Personal Dosimeters
INFO-0744—Guidelines for Handling Packages Containing Nuclear Substances
G-129 rev. 1—Keeping Radiation Exposures and Doses "As Low as Reasonably Achievable"
R-117—Requirements for Gamma Radiation Survey Meter Calibration
R-116—Requirements for Leak Testing Selected Sealed Radiation Sources