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X-RAY RADIATION SAFETY

Operator Training Manual

Handheld XRF

Innovation with Integrity

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1. Training Objectives

- Describe occupation radiation worker rights and responsibilities
- Describe Ionizing Radiation
- Describe the nature and properties of X-Ray radiation and its associated hazards
- Describe how X-Rays are produced
- Describe the biological effects of exposure to X-Rays
- Describe the X-Ray exposure potential of the Bruker Handheld XRF Analyzer
- Identify and describe personnel monitoring devices
- Identify and describe radiation survey instruments
- Describe the principles of radiation protection and ALARA
- Describe the designed safety features in the Bruker Handheld XRF Analyzer
- Describe the proper operating procedure for the Bruker Handheld XRF Analyzer
- Identify failure of designed safety features or other unusual conditions
- Describe XRF Analyzer user responsibilities
- Describe the Federal Regulatory Dose Limits
- List the common sense rules for safely operating the Bruker Handheld XRF Analyzer

The Bruker Handheld XRF Analyzer user's training consists of this manual, the User Guide, the Basic Operation Training Video, and the Radiation Safety Video. A PowerPoint presentation and the instructor may also supplement these training materials. Proper training is vital for compliance, safe operation, and understanding of the responsibilities of the user of handheld XRF analyzers. Some local regulatory agencies require that training be documented and a demonstration of sufficient knowledge through an examination be performed.

Bruker recommends that local regulatory requirements in regards to training be determined, understood, and followed.

2. What is Radiation?

The term ***radiation*** is used with all forms of energy—light, X-rays, radar, microwaves, and more. For the purpose of this manual, however, radiation refers to invisible waves or particles of energy from radioactive sources or X-ray tubes. High levels of radiation may pose a danger to living tissue because it has the potential to damage and/or alter the chemical structure of cells. This could result in various levels of illness (mild to severe).

The user of a Bruker XRF analyzer must understand the nature of radiation and how to safely use XRF analyzers.

3. Radiation Terminology

Before examining the subject of radiation in more detail, there are several important terms to be reviewed and understood.

Bremsstrahlung: The X-rays or "braking" radiation produced by the deceleration of electrons, namely in an X-ray tube.

Characteristic X-rays: X-rays emitted from electrons during electron shell transfers.

Fail-Safe Design: One in which all failures of indicator or safety components that can reasonably be anticipated cause the equipment to fail in a mode such that personnel are safe from exposure to radiation. For example, if the red lamp indicating "X-RAY ON" fails, the production of X-rays would be prevented.

Ion: An atom that has lost or gained an electron.

Ion Pair: A free electron and positively charged atom.

Ionization: The process of removing electrons from the shells of neutral atoms.

Ionizing Radiation: Radiation that has enough energy to remove electrons from neutral atoms.

Isotope: Atoms of the same element that have a different number of neutrons in the nucleus.

Non-ionizing Radiation: Radiation that does not have enough energy to remove electrons from neutral atoms.

Normal Operation: Operation under conditions suitable for collecting data as recommended by manufacturer, including shielding and barriers.

Primary Beam: Ionizing radiation from an X-ray tube that is directed through an aperture in the radiation source housing for use in conducting X-ray fluorescence measurements.

Radiation: The energy in transit in form of electromagnetic waves or particles.

Radiation Generating Machine: A device that generates X-rays by accelerating electrons, which strike an anode.

Radiation Source: An X-ray tube or radioactive isotope.

Radiation Source Housing: That portion of an X-ray fluorescence (XRF) system, which contains the X-ray tube or radioactive isotope.

Radioactive Material: Any material or substance that has unstable atoms, which are emitting radiation.

System Barrier: That portion of an area, which clearly defines the transition from a controlled area to a radiation area and provides the necessary shielding to limit the dose rate in the controlled area during normal operation.

X-ray Generator: That portion of an X-ray system that provides the accelerating voltage and current for the X-ray tube.

X-ray System: Apparatus for generating and using ionizing radiation, including all X-ray accessory apparatus, such as accelerating voltage and current for the X-ray tube and any needed shielding.

4. Types of Radiation

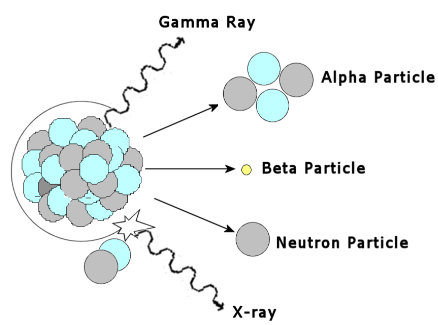
As stated earlier, radiation consists of invisible waves or particles of energy that could have a health effect on humans if received in too large a quantity. There are two distinct types of radiation: *non-ionizing* and *ionizing*.

4.1. Non-ionizing Radiation

Non-ionizing radiation does not have the energy needed to ionize an atom (i.e. to remove electrons from neutral atoms). Sources of non-ionizing radiation include light, microwaves, power lines, and radar. Although this type of radiation can cause biological damage, like sunburn, it is generally considered less hazardous than ionizing radiation.

4.2. Ionizing Radiation

Ionizing radiation has enough energy to remove electrons from neutral atoms in a process called ***ionization***. An atom having either a positive or negative charge is an ion. A free electron is also an ion. Ionizing radiation is of concern due to its potential to alter the chemical structure of living cells. These changes can alter or impair the normal functions of a cell. Sufficient amounts of ionizing radiation can cause hair loss, blood changes, and varying degrees of illness. These levels are approximately 1,000 times higher than levels that the public or workers are permitted to receive.



The four basic types of ionizing radiation are emitted from different parts of an atom, as shown in the image to the right.

***NOTE**: Bruker handheld XRF devices only emit X-rays.*

Alpha Particles have a large mass, consisting of two protons and two neutrons, and a positive charge. They ionize by stripping away electrons (-) from other atoms with its positive (+) charge, and are generally only considered a radiation hazard if ingested or inhaled.

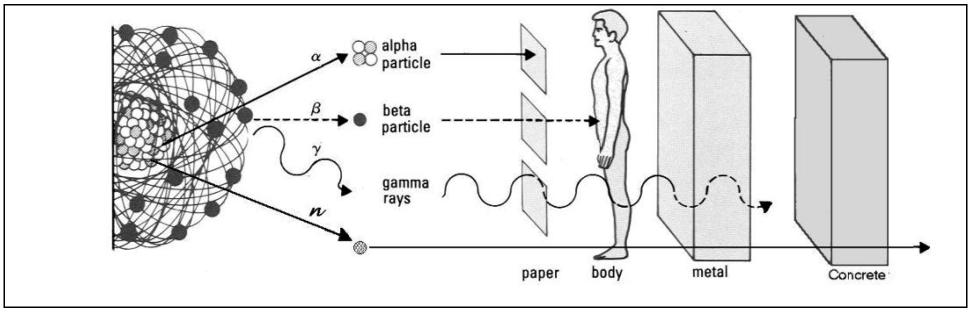
Beta Particles are high-energy, high-speed electrons or positrons which form ionizing radiation also known as beta rays. They ionize other atoms by stripping electrons out of their orbits with their negative charge, and are primarily a radiation hazard only to the skin and eyes.

Gamma Rays and X-rays are electromagnetic waves or photons of pure energy that have no mass or electrical charge. They ionize atoms by interacting with electrons, and are best shielded by use of dense materials, such as concrete, lead, or steel. Bruker handheld devices produce X-rays.

Neutron Particles are ejected from the nucleus of an atom during the normal operation of a nuclear reactor or particle accelerator, as well as the natural decay process of some radioactive elements. They can split atoms by colliding with their nuclei, forming two or more unstable atoms and cause ionization as they try to become stable. They are best shielded by materials with a high hydrogen content (water, concrete or plastic).

4.3. Penetration

The penetrating power for each of the four basic radiations varies significantly, as shown below.



5. Units for Measuring Radiation

The absorption of radiation into the body, or anything else, depends upon two things: the type of radiation involved and the amount of radiation energy received. Internationally, the units for measuring radiation are the *Gray* and *Sievert*; in the USA, the units are the *rad* and *rem*.

5.1. Rad (Radiation Absorbed Dose)

A rad is:

- A unit for measuring the amount of radiation energy absorbed by a material (i.e., dose)
- Defined for any material (e.g., 100 ergs/gm)
- Applied to all types of radiation
- Not related to biological effects of radiation in the body
- 1 rad = 1000 millirad (mrad)
  - The Gray (Gy) is the System International (SI) unit for absorbed energy
  - 1 rad = 0.01 Gray (Gy) and 1 Gray = 100 rad

5.2. Rem

Actual biological damage depends upon the concentration as well as the amount of radiation energy deposited in the body. The rem is used to quantify overall doses of radiation, their ability to cause damage, and their dose equivalence (see below).

A rem is:

- Is a unit for measuring dose equivalence
- Is the most commonly used unit of radiation exposure measure
- A term that pertains directly to humans
- Takes into account the energy absorbed (dose); the quality of radiation; the biological effect of different types of radiation in the body and any other factor.

For gamma and X-ray radiation all of these factors are unity so that for these purposes a rad and a rem are equal.

- 1 rem = 1000 millirem (mrem)
    - Sievert is the SI unit for dose equivalence
    - 1 rem = 0.01 Sievert (Sv) and 1Sv = 100 rem

5.3. Dose and Dose Rate

Dose is the amount of radiation you receive during any exposure.

Dose Rate is the rate at which you receive the dose.

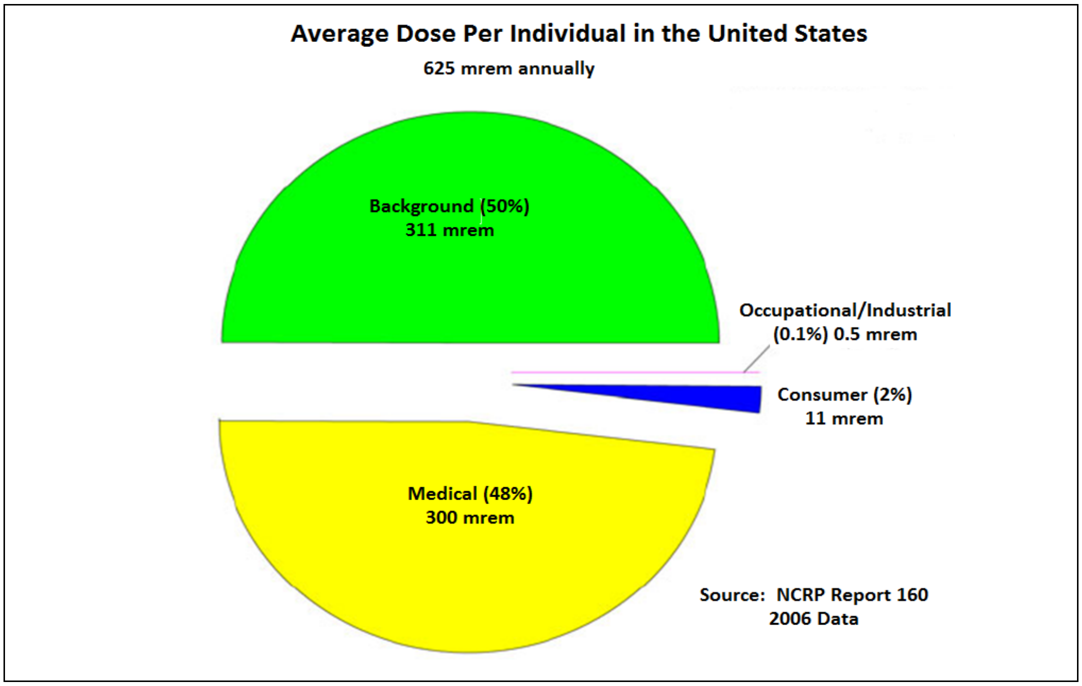
***Example**:*
Dose rate = dose/time = mrem/hr
Dose = dose rate x time = mrem

6. Significant Doses

Typical Radiation Doses from Selected Sources (Annual)*	
Exposure Source	**mrem per year**
Background (50%)	311
Medical (48%)	300
Consumer (2%)	13
Occupational (0.1%)	0.5
Round trip US by air	5
Building materials	3.6
Worldwide fallout	<1
Natural gas range	0.2
Smoke detectors	0.0001
** Based on 2006 U.S. data only*	

Average Occupational Doses	
Occupation	**Exposure (mrem per year)**
Airline flight crewmember	1000
Nuclear power plant worker	700
Grand central station worker	120
Medical personnel	70
DOE/DOE contractors	44

NCRP Report No. 160, *Ionizing Radiation Exposure of the Population of the United States*, published in 2006, summaries the effective dose per individual in the U.S. population as 625 mrem annually. This number has increased over the previous value of 360 mrem primarily due to the increased radiation exposure from medical procedures.



As previously stated, the general public is exposed daily to small amounts of radiation. However, there are four major groups of people that have been exposed in the past to significant levels of radiation. Because of this we know much about ionizing radiation and its biological effects on the body. The earliest radiation workers, such as radiologists, received large doses of radiation before biological effects were recognized. Since then, safety standards have been developed to protect such employees.

The more than 100,000 people who survived the atomic bombs dropped on Hiroshima and Nagasaki, those involved in accidents like Chernobyl, and those who have received radiation therapy for cancer are examples of large groups that have received significant doses of radiation.

7. Biological Effects of Radiation

7.1. Cell Sensitivity

The human body is composed of billions of living cells. Groups of these cells make up tissues, which in turn make up the body's organs. Some cells are more resistant to viruses, poisons, and physical damage than others. Rapidly dividing cells are the most sensitive cells, which is why exposure to a fetus is so carefully controlled. Radiation damage may depend on both resistance and level of activity during exposure.

7.2. Acute and Chronic Doses of Radiation

All radiation, if received in sufficient quantities, can damage living tissue. The key lies in how much and how quickly a radiation dose is received. Doses of radiation fall into one of two categories: acute or chronic.

Acute Dose
An acute dose is a large dose of radiation received in a short period of time that results in physical reactions due to massive cell damage (acute effects). The body can't replace or repair cells fast enough to undo the damage right away, so the individual may remain ill for a long period of time. Acute doses of radiation can result in reduced blood count and hair loss. Recorded whole body doses of 100 – 250 mSv (10 - 25 rem) have resulted only in slight blood changes with no other apparent effects.

Radiation Sickness
Radiation sickness may occur at acute doses greater than 1 Sv (100 rem.) Radiation therapy patients often experience it as a side effect of high-level exposures to singular areas. Radiation sickness may cause nausea (from cell damage to the intestinal lining), and additional symptoms such as fatigue, vomiting, increased temperature, and reduced white blood cell count.

Acute Dose to the Whole Body
Recovery from an acute dose to the whole body may require a number of months. Whole body doses of 5 Sv (500 rem) or more may result in damage too great for the body to recover.

Example*: 30 firefighters at the Chernobyl facility lost their lives as a result of severe burns and acute radiation doses exceeding 8 Sv (800 rem.)*

Only extreme cases (as mentioned above) result in doses so high that recovery is unlikely.

Acute Dose to Part of the Body
Acute dose to a part of the body most commonly occur in industry (use of X-ray machines), and often involve exposure of extremities (hand, fingers, etc.). Sufficient radiation doses may result in loss of the exposed body part. The prevention of acute doses to part of the body is one of the most important reasons for proper training of personnel.

Chronic Dose
A chronic dose is a small amount of radiation received continually over a long period of time, such as the dose of radiation we receive from natural background sources every day.

Chronic Dose vs. Acute
The body tolerates chronic doses better than acute doses because only a small number of cells need repair at any one time. Also, since radical physical changes do not occur as with acute doses, the body has more time to replace dead or non-working cells with new ones.

Genetic Effects
Genetic effects involve changes in chromosomes or direct irradiation of the fetus. Effects can be somatic (cancer, tumors, etc.) and may be heritable (passed on to offspring).

Somatic Effects
Somatic effects apply directly to the person exposed, where damage has occurred to the genetic material of a cell that could eventually change it to a cancer cell. It should be noted that the chance of this occurring at occupational doses is very low.

Heritable Effects
This effect applies to the offspring of the individual exposed, where damage has occurred to genetic material that doesn't affect the person exposed, but will be passed on to offspring.

To date, only plants and animals have exhibited signs of heritable effects from radiation. This data includes the 77,000 children born to the survivors of Hiroshima and Nagasaki. The studies performed followed three generations, which included these children, their children, and their grandchildren.

7.3. Biological Damage Factors

Biological damage factors are those factors that directly determine how much damage living tissue receives from radiation exposure, including:

- **Total dose**: the larger the dose, the greater the biological effects
- **Dose rate**: the faster the dose is received, the less time for the cell to repair
- **Type of radiation**: the more energy deposited the greater the effect
- **Area exposed**: the more body area exposed, the greater the biological effects
- **Cell sensitivity**: rapidly dividing cells (e.g., eyes) are the most vulnerable
- **Individual sensitivity**: some individuals are more sensitive than others

Individuals sensitive to ionizing radiation:

- Developing embryo/fetus is the most sensitive
- Children are the second most vulnerable
- The elderly are more sensitive than middle-aged adults
- Young to middle-aged adults are the least sensitive

Bruker analyzers, if used in accordance with manufacturer's instructions, do not pose any significant threat of exposure to the operator. Because an embryo/fetus is most susceptible to ionizing radiation, special rules have been developed for pregnant workers. See Section 8.2.1.

8. Putting Risks in Perspective

Acceptance of any risk is a very personal matter and requires that a person make informed judgments, weighing benefits against potential hazards.

8.1. Risk Comparison

The following summarizes the risks of radiation exposure:

- The risks of low levels of radiation exposure are still unknown.
- Since ionizing radiation can damage chromosomes of a cell, incomplete repair may result in the development of cancerous cells.
- There have been no observed increases of cancer among individuals exposed to occupational levels of ionizing radiation.
- Using other occupational risks and hazards as guidelines, nearly all scientific studies have concluded the risks of occupational radiation doses are acceptable by comparison.

Average Estimated Days Lost By Industrial Occupations	
Occupation*	**Estimated Days Lost**
Mining/Quarrying	328
Construction	302
Agriculture	277
Transportation/Utilities	164
5 rem radiation dose per yr for 30 years	150
All industry	74
Government	55
Service	47
Manufacturing	43
Trade	30

Average Lifetime Estimated Days Lost Due to Daily Activities	
Activity*	**Estimated Days Lost**
Cigarette smoking	2250
25% Overweight	1100
Accidents (all types)	435
Alcohol consumption (U.S. avg.)	365
Driving a motor vehicle	207
Medical X-rays (U.S. avg.)	6
1 rem Occupational Exposure	1
1 rem per year for 30 years	30

** **Note**: based on US data only*

The comparison of health and industrial risks illustrates the fact that no matter what you do there is always some associated risk. For every risk there is some benefit, so you as the worker must weigh these risks and determine if the risk is worth the benefit. Exposure to ionizing radiation is a consequence of the regular use of many beneficial materials, services, and products. By learning to respect and work safely around radiation, we can effectively manage our exposure.

8.2. Radiation Dose Limits

To minimize risks from the potential biological effects of radiation, regulatory agencies and authoritative bodies have established radiation dose limits for occupational workers. These limits apply to those working under the provisions of a specific license or registration.

In general, the larger the area of the body that is exposed, the greater the biological effects for a given dose. Extremities are less sensitive than internal organs because they do not contain critical organs. That is why the annual dose limit for extremities is higher than for a whole body exposure that irradiates the internal organs.

Your employer may have additional guidelines and set administrative control levels. Each employee should be aware of such additional requirements to do their job safely and efficiently. The limits described below have been developed based on information and guidance from the International Commission on Radiological Protection (ICRP-1990), the Biological Effects of Ionizing Radiation (BEIR) Committee, the US Environmental Protection Agency (EPA), and the National Council of Radiation Protection (NCRP). For an XRF analyzer using an X-ray tube as the source, any requirement on dose limits for the operators would be established by the appropriate regulatory agency.

Annual Occupational Dose Limits		
Exposed Area	**International**	**U.S.**
Whole Body	20 mSv*	5 rem
Extremities	500 mSv	50 rem
Organs or Tissue *(Excluding lens of the eye and skin)*	500 mSv	50 rem
Lens of the Eye	150 mSv	15 rem

**Averaged over 5 years*

8.2.1. Declared Pregnant Worker

A female radiation worker may inform her supervisor of her pregnancy, in writing, at which time she becomes a Declared Pregnant Worker. The employer should then provide the option of a mutually agreeable assignment of work tasks, without loss of pay or promotional opportunity, such that further radiation exposure will not exceed the dose limits as shown in the following table for the declared pregnant worker.

Radiation Limits for Visitors, Public, and Pregnant Workers	
International and US Limit	1 mSv (100 mrem) per year
Pregnant Worker (International Limit)	2 mSv (200 mrem) to abdomen during remainder of gestation period after declaration
Pregnant Worker (US Limit)	Declared Pregnant Worker (embryo / fetus) - 0.5 rem / 9 months (≈ 0.05 rem / month)

The radiation produced by the hand-held XRF analyzer from the primary beam is low energy X-Rays (4 to 50 keV) in a narrow collimated beam. The radiation exposure to the user is primarily from scattered radiation from the objects being analyzed and a small amount of radiation that passes through the housing. When correctly using the XRF Analyzer, its engineered safety features ensure radiation exposure will be significantly less than the annual limits.

9. Measuring Radiation

Because we cannot detect radiation through our senses, special devices may be required in some jurisdictions for personnel operating an XRF Analyzer to monitor and record the operator's exposure. These devices are commonly referred to as dosimeters, and the use of them for monitoring is called dosimetry.

The following information may apply to personnel using hand-held XRF analyzers in jurisdictions where dosimetry is required:

- Wear an appropriate dosimeter that can record low energy photon (X-ray) radiation.
- Dosimeters wear period of three months may be used, subject to local regulation.
- Each dosimeter will be assigned to a particular person and is not to be used by anyone else.
- Whole body dosimetry should be worn on the upper portion of your body between the neck and waist.
- Extremity dosimeters should be worn on the fingers or wrist closest to the XRF analyzer and is most importantly used on the hand not holding the analyzer.
- Do not intentionally expose a dosimeter to the primary beam.
- Do not expose you dosimeter to radiation outside of work (e.g., medical facilities and dentist offices).
- Do not put you dosimeter in checked or hand carried luggage when traveling through airports.
- If your dosimeter is damaged or lost, notify your supervisor and/or RSO.

Bruker recommends that local regulatory requirements in regards to occupational radiation monitoring be determined, understood, and followed.

9.1. Dosimeters

While there is variation between dosimeters, and from one type to another, most dosimeters operate in a similar way. Exposure to ionizing radiation is absorbed by a material contained within the dosimeter and, when processed, provides a measured dose. Regulators require that processing of dosimeters be performed by a company that is NVLAP accredited. Monitoring radiation exposure with dosimeters provides an indication of the working habits and working conditions of the XRF user and may be a way to identify whether the XRF analyzer is being properly used. **Remember**: a dosimeter does not protect you against radiation exposure; it is simply a passive device that measures the amount of radiation exposure received where the dosimeter was worn. The figure below shows various types of dosimeters available.

Whole Body Dosimeter

A Thermoluminescent Device (TLD) or Optically Simulated Luminescence (OSL) whole-body dosimeter may be used to measure both shallow and deep penetrating radiation doses. It is normally worn between the neck and waist. The measured dose recorded by this device may be used as an individual's legal occupational exposure.

Finger Ring

A finger ring is a TLD in the shape of a ring, which is worn by workers to measure the radiation exposure to the extremities. The measured dose recorded by this device may be used as the worker's legal occupational extremity exposure.

Wrist Dosimeter

A wrist dosimeter is a whole-body type dosimeter that is designed to be worm on the wrist similarly to a wrist watch. Processing of the dose takes into account where the dosimeter is worn and measures the radiation exposure to the extremities. The measured dose recorded by this device may be used as the worker's legal occupational extremity exposure.

9.2. Survey Meters

Some jurisdictions require the measurement of radiation emitted or scattered from handheld analyzers by the use of a survey meter, which detects radiation in real time. Survey meters generally consist of a detector and a read-out display. Commonly used survey meters are the ***ionization chamber***, ***Geiger-Mueller (GM) tube,*** and ***photomultiplier tube scintillation detector***. It is important to select a suitable instrument that is capable of monitoring the type, energy, and intensity of ionizing radiation produced by the hand-held XRF analyzer. The hand-held XRF analyzer produces low energy X-ray ionizing radiation. The energy of the X-rays produced by the analyzer will be between 4 keV and 50 keV, with the average energy near 20 to 30 keV, and most of the X-ray energy being less than this due to effects of scattering which significantly reduces the X-ray energy.

The GM tube instrument has the advantage of being economical and sensitive to low levels of radiation. This instrument is good at identifying and isolating hot spots. However, an instrument using a GM tube detector usually does not do well in providing accurate dose rate measurements, unless specifically designed to do so. In such cases, a specially designed filter is used to flatten out the energy response.

The ionization chamber is often a preferred instrument. The detector response is relatively flat across its entire measurement range. The disadvantage is these instruments are often more expensive and do not read out in the desired or useful measurement ranges. Their large detector volumes can be challenging because the measurement results are usually affected by geometry factors and the displayed dose rate is often much less than the actual field at close distances.

The low energy plastic scintillator dose rate instrument uses a plastic detector that is nearly tissue equivalent. This type of instrument has the advantage of being sensitive and providing accurate results. One disadvantage is this type of instrument is typically more expensive than the other instrument types.

If your jurisdiction requires the use of a survey meter, we recommend that you work with your preferred instrument provider to identify a suitable survey meter for your application. Survey instruments are used to provide information to assure that doses are kept ALARA and to verify the integrity of the XRF Analyzer designed shielding has not been compromised. The following characteristics should be used to assist in selecting an appropriate instrument.

- Radiation type: X-rays
- Energy range: 4 to 50 keV
- Measurement threshold: 0.01 mem/hr to 200 mrem/hour
- Accuracy: ± 10% of reading or better

Consult the meter’s user guide for proper calibration. Remember the instrument should be calibrated to the type and energy of the radiation being monitored. The manufacturer may require the use of correction factors to obtain accurate results for the energy of the X-rays produced by the XRF analyzer.

We recommend that primary beam measurements never be attempted. Our safety representatives will work with you to provide information about the primary beam should you need more information than is provided in our manuals.

10. Exposure Reduction (ALARA)

While dose limits and administrative control levels already ensure very low radiation doses, it is possible to reduce these exposures even more. The main goal of the ALARA program is to reduce ionizing radiation doses to a level that is As Low As Reasonably Achievable (ALARA). ALARA is designed to prevent unnecessary exposures to employees, the public, and to protect the environment. It is the responsibility of all workers, managers, and safety personnel alike to ensure that radiation doses are maintained ALARA.

There are three basic practices to maintain external radiation ALARA: ***Time, Distance, and Shielding.***

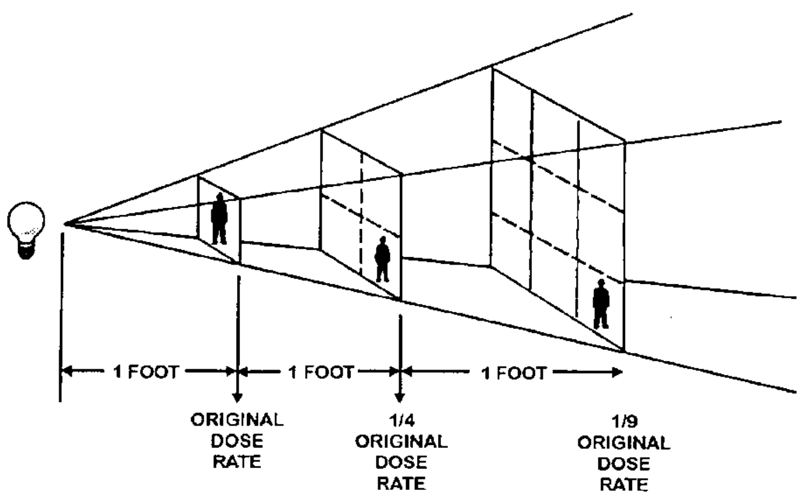
<u>Time</u>
The first method of reducing exposure is to limit the amount of time spent in a radioactive area. Generally, the shorter the time, the lesser the amount of exposure.

The effect of time on radiation could be stated as

Dose = Dose Rate x Time

Example*: If 1 hour of time in an area results in 1 mSv (100 mrem) of radiation, then 1/2 an hour results in 0.5 mSv (50 mrem), and 1/4 an hour would result in 0.25 mSv (25 mrem), and so on.*

<u>Distance</u>
The second method for reducing exposure is by maintaining the maximum possible distance from the radiation source to the operator or member of the public. The principle of distance is that the exposure rate is reduced as the distance from the source is increased. The greater the distance, the amount of radiation received is reduced. This method can best be expressed by the Inverse Square Law.



The inverse square law states that doubling the distance from a point source reduces the dose rate (intensity) to 1/4 of the original. Tripling the distance reduces the dose rate to 1/9 of its original value. Expressed mathematically:

$$C \times \frac{D_1^2}{D_2^2} = I$$

Where:

- C is the intensity (dose rate) of the radiation source
- D_1 is the distance at which C was measured
- D_2 is the distance from the source
- I is the new level of intensity at distance D_2 from the source

The inverse square law does not apply to sources of greater than a 10:1 (distance: source size) ratio, or to the radiation fields produced from multiple sources.

Shielding

The third, and perhaps most important, method of reducing exposure is shielding. Shielding is generally considered to be the most effective method of reducing radiation exposure, and consists of using a material to absorb or scatter the radiation emitted from a source before it reaches an individual.

As stated earlier, different materials are more effective against certain types of radiation than others. The shielding ability of a material also depends on its density, or the weight of a material per unit of volume.

> ***Example****: A cubic foot of lead is heavier than the same volume of concrete, and so it would also be a better shield.*

Although shielding may provide the best protection from radiation exposure, there are still several precautions to keep in mind when using handheld XRF devices:

- Persons outside the shadow cast by the shield are not necessarily 100% protected. **Note**: All persons not directly involved in operating the XRF should be kept at least three feet away.
- A wall or partition may not be a safe shield for persons on the other side.
- Scattered radiation may bounce around corners and reach nearby individuals, whether or not they are directly in line with the test location.

> ***WARNING****: To avoid inadvertent exposure to others, the operator should ensure that there is no one on the other side of the wall or barrier when using an XRF analyzer.*

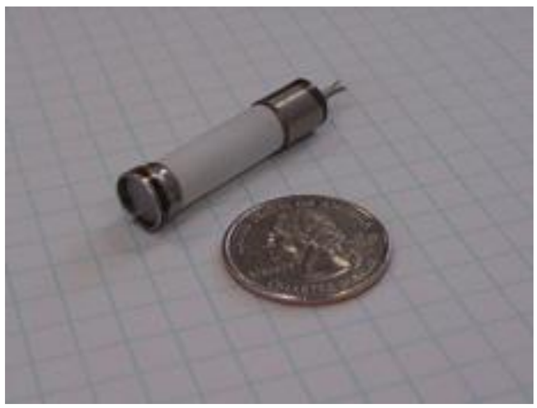
11. Production of X-Ray Radiation

X-rays are produced by two separate processes:

- Bremsstrahlung: continuous energy spectrum, process = acceleration of electron
- Characteristic: single energy line, process = electron shell transition

Bremsstrahlung is the German term for "braking" and was originally used to describe the unknown penetrating radiation (X-rays) released when high-speed electrons were stopped by sudden impact with a metal target. X-ray tubes are designed to use this process to create X-rays.

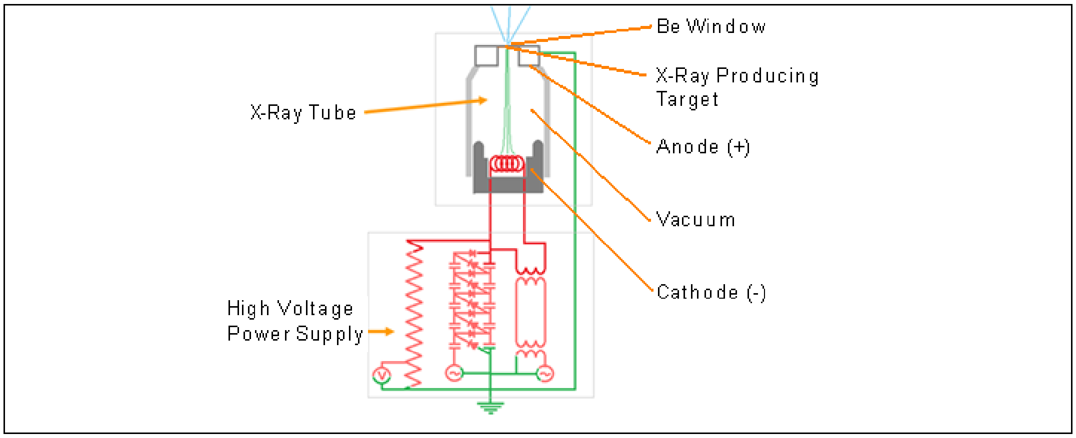
A modern miniature industrial X-ray tube consists of a ceramic container that is under vacuum. The major components of a miniature X-Ray tube is the cathode and anode housed in a vacuum ceramic tube. High voltage bias is applied between the anode (+) and the cathode (-). The picture below is representative of the type of X-Ray tube used in the hand-held XRF analyzer.



A current passed through a miniature coiled tungsten filament raises the temperature of the wire to approximately 1000°K, causing the thermionic emission of electrons. Typical currents of 5 to 100 µ amps of current are used depending on the type of analysis being conducted.

The electrons emitted from the tungsten filament passes through the vacuum of the tube and are accelerated as they are attracted to the positive charge of the anode. The large voltage potential of 40 to 50 keV transfers a large amount of energy to the electrons.

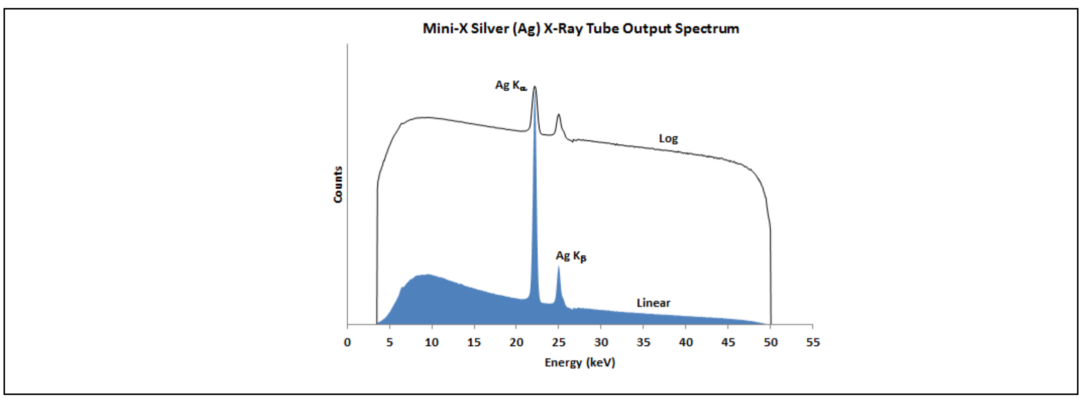
The electrons having gained a huge amount of kinetic energy impact the X-ray producing target. The targets are usually made of Rhodium (Rh) or Silver (Ag) in the X-ray tubes used for handheld XRF analyzers. The impaction of electrons on the target knocks a lower orbit electron from the target atoms lower shell creating a void. A higher shell electron moves to fill the void, releasing its extra energy in the form of an X-ray photon. This produces the X-rays required to conduct XRF analysis. The figure below provides a diagram of a typical X-ray tube used in our application.



The current applied to the filament changes the intensity of the X-ray by changing the number of electrons emitted from the miniature coiled tungsten filament. More current means more electrons.

The voltage controls the energy of the X-rays. More voltage means higher energy X-rays.

A typical hand-held XRF analyzer X-ray tube will emit x-rays from 8 keV to 50 keV with the maximum intensity occurring at about one-half the maximum keV. The X-ray spectrum will be distributed across a continuum of energies. The figure below provides an example of a typical X-ray spectrum.



X-Ray production voltage and current settings in the handheld XRF Analyzer has been programmed to produce the energy and intensity required to obtain the best analysis results for a particular application. The user does not make any voltage or current adjustments in operating the XRF analyzer.

12. Radiation Exposure Potential

Note
The following section uses the S1 TITAN as an example. The dose rate is typical of handheld XRF instruments. For specific information on a particular instrument, see the instrument's User Guide.

The potential for exposure to ionizing radiation is primarily from scattered radiation from the objects being analyzed and small amounts of radiation from the analyzer's housing. The potential exists for exposure to the primary beam if the XRF analyzer is not operated properly, with the greatest potential being to the operator's fingers and hands. Table 1 provides the exposure potential of the S1 TITAN when operated at its maximum voltage setting.

Table 1

Distance (cm)	Rad/hr	Deep Dose (Rem/hr)	Shallow Dose (Rem/hr)
Beam Port	4610	3642	5071
5 cm	398	314	438
10 cm	126	99.5	139
30 cm	18	14.2	19.8
100 cm	1.01	0.80	1.11

Table 2 lists the amount of time that it would take to reach the annual limits if the S1 TITAN is operated with the beam port against a body part at its maximum power setting. The time to reach these annual limits is quite short.

Table 2

Organ	Eye	Skin
Annual Limit	15 Rem	50 Rem
Time (minutes)	0.17	0.59

Table 3 lists the biological effects and typical dose and time to see the effects from exposure to the primary beam.

Table 3

Skin Effect	Dose (Rad)	Time (minutes)
Erythema (Redding of Skin)	300	3.9
Dry Desquamation	1000	13.0
Wet Desquamation / Blistering	1500	19.5
Ulceration and Necrosis	3000	39.0

The effects of ionizing radiation exposure to the skin may only appear days or weeks after the exposure. This is because the radiation damages the developing cells below the skin surface. The damage cannot be observed until the top layers of the skin slough off.

- **Erythema** is redness of the skin, caused by hyperemia of the capillaries in the lower layers of the skin.
- **Dry Desquamation** also called **skin peeling** is the shedding of the outermost membrane or layer of a skin.

- **Wet desquamation** is where the skin thins and then begins to weep because of loss of integrity of the epithelial barrier and decreased oncotic pressure.

There have been no documented radiation related injuries from hand-held XRF analyzer operations. The potential exists for injury to the fingers or hands if safety features are disabled and/or proper operating instructions are not followed. There have been documented injuries which have occurred from **not** following proper operating procedures and bypassing safety features on cabinet analytical systems.

It is important to note that although the annual limits could be reached fairly easily through accidental exposures through improper use of the XRF analyzer, the skin effects caused by exposures would take significant more time than might occur through a momentary lapse of proper operation.

13. Rights and Responsibilities

Individuals who work with ionizing radiation producing equipment, such as the handheld XRF analyzer, have certain rights and responsibilities. These rights and responsibilities are usually specifically defined by the jurisdiction that the XRF analyzer is registered under.

If you are required to wear a dosimeter, you have the right to be informed of the occupational exposure you receive. Typically, your employer is required to provide a report of your previous year's exposure during the 1st quarter of the next year

Users of handheld XRF analyzers have the responsibility to obey warning labels and follow the operator training. You are required to follow the rules and regulations governing the operation of a portable XRF. This is for your protection and the protection of co-workers, clients, and the public. Typically, you are required to report concerns and violations to your supervisor and regulatory authorities

Most jurisdictions require that individuals working under their rules and regulations never deliberately cause a violation of any related rule or regulation. Deliberate violations usually are subject to enforcement action. Mistakes and unplanned action usually do not apply.

Prior to using the handheld XRF analyzer, carefully read the instrument's user guide.

As the operator of the handheld XRF analyzer, you are responsible for your safety and the safety of others. The following are important responsibilities:

- Before pulling the trigger, be aware of the direction that the X-rays travel.
- Do not place any part of your body (especially the eyes or hands) near the examination area during measurement.
- Do not hold a sample to the window for analysis by hand. Instead, hold the window to the sample. The infrared (IR) sensor located on the nose is designed to prevent the emission of X-rays in the absence of an object.
- Do not defeat the IR sensor in order to bypass the safety circuit. Defeating this safety feature could result in unnecessary exposure of the operator. Occasionally, a sample may not be reflective enough to trigger the IR sensor. In these cases, place a piece of white paper or other reflective material between the sample and IR sensor.
- Use the optional safety shield or benchtop stand accessory for testing small or thin samples or low-density materials, such as plastic, wood, soil, paper, or ceramics.

- Wear an appropriate dosimeter if required by a regulatory agency when operating the analyzer.
- Pregnant women should be aware that improper handling or improper use of the instrument could result in radiation exposure.
- The operator is responsible for the security of the analyzer. When in use, the device should be in the operator's possession at all times.
- Do not allow anyone other than trained and certified personnel to operate the analyzer.
- Always store the instrument in a secure location when not in use.
- If you suspect the analyzer is damaged, remove the battery pack and disconnect all power sources.

14. Backscatter with Low Density Samples

Be aware that when using a handheld XRF analyzer, some radiation is scattered back towards the operator. The amount of scatter is dependent on the density of the sample – with low density samples, such as plastics, scattering more than high density samples, such as metals – and the shape of the sample – with flat surfaces containing more of the backscatter and curved and irregular surfaces containing less of the backscatter. The operator must keep hands and eyes away from the analyzer nosepiece.

Further, it should be noted that low-density (LD) materials, such as plastic, wood, soil, paper, or ceramic, will not attenuate higher energy X-rays as efficiently as high-density materials, such as metal alloys. Thus a greater amount of the radiation is transmitted through the sample, which can cause a higher dose rate to the operator. The operator should keep hands and eyes away from the analyzer nosepiece. If LD samples are measured frequently, the use of a bench-top stand is recommended to minimize scattered radiation. If the LD samples are small enough, the Small Sample Safety Shield is adequate.