Department of
Environment &
Conservation

Environmental Show of the South

Division of Radiological Health

Department of Environment & Conservation

- X-ray Fluorescence (XRF) Used in Industrial, Landfill, and Scrap Metal Industries
- X-ray Devices Used for Security
- X-ray Devices Used for Bomb Squad Applications
- X-ray Devices Used in Personal Security Screening Systems

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Analytical Fluorescence

Analytical Fluorescence is considered **non-destructive testing** (NDT), meaning the sample is not changed during testing.

Fluorescence analysis can be:

qualitative
(determining what elements are present),

And/or

quantitative
(determining how much of each element is present).

X-ray Fluorescence – Qualitative Analysis

X-Ray Fluorescence (sometimes abbreviated as XRF) can be considered in a four step process occurring at the atomic level:

1. Electrons in an 'shell' around the nucleus are held in place with a specific energy. It takes more energy to hold an electron in an outer shell than in an inner shell.

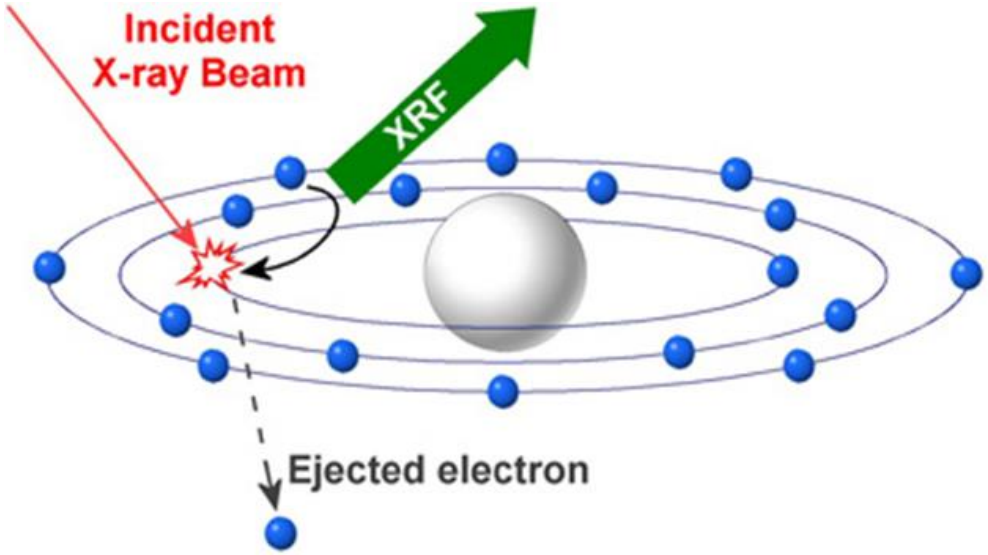
2. An incoming X-Ray knocks out an electron from one of the orbitals surrounding the nucleus within an atom of the material. This requires an incoming x-ray energy of 10 – 50 kilovolts (kV).

3. When the electron is knocked out, a 'hole' is produced in the orbital, resulting in a high energy, unstable configuration for the atom.

4. To restore equilibrium, an electron from a higher energy, outer orbital falls into the hole. Since this is a lower energy position, the excess energy is emitted in the form of a fluorescent X-Ray

X-ray Fluorescence - Qualitative Analysis

The energy difference between the expelled and replacement electrons is characteristic of the element atom in which the fluorescence process is occurring – thus, **the energy of the emitted fluorescent X-Ray is directly linked to a specific element being analyzed**. It is this key feature which makes XRF such a fast analytical tool for elemental composition.



X-ray Fluorescence – Quantitative Analysis

- When a sample containing an element is irradiated by the primary beam x-ray, the intensity of the generated fluorescent x-ray of element is dependent on its fraction in the sample. The higher fraction of element in the sample, results in a higher intensity of the fluorescent x-ray that is generated. Taking this into account, the volume fraction (percent of the sample) of certain element can be determined knowing the respective fluorescent x-ray intensity.

So analytical devices can tell you what is there (qualitative) and how much is there (quantitative).

Benchtop Analytical

In the past, the only way this analysis could be performed was to take the sample into the laboratory and place the sample into the analytical device (benchtop).

Sample chamber port (where you put your sample

Control panel and display

The benchtop device is still the standard for laboratory analysis.

?

But what if your sample is a 30 foot long pipe?

“If you can’t get Mohamad to the mountain, you get the mountain to Mohamad.”

The Portable, Hand-held Analytical X-ray

And, thus, the portable XRF is born.

X-ray Fluorescence - Examples Uses

At a recycle facility or scrap yard, these XRF devices can let the yard know what they are getting without guessing. It can also let them know the quality of the metal, such as the carbon content of a piece of steel; the higher the carbon content, the higher the grade of steel, and the higher the price they can received when recycling. Or the grade of gold, 10 carrot verses 24 carrot; a big difference in price!

A subcontractor may have certain specifications for a product they produce for a contractor. For example, the specs may call for the product to be a certain grade material. When the subcontractor receives raw material, they can use the portable XRF device to determine the quality of the incoming raw material. Also, the prime contractor can use the x-ray device as a QC on the incoming product from the subcontractor.

X-ray Fluorescence (XRF)

From a regulatory perspective, there are 2 distinctions in analytical x-ray devices:

Open-beam vs. Closed-beam;

Fixed (benchtop) vs. Hand-held.

* ‘Open-beam’ means you could place your hand in the primary beam; therefore, closed-beam devices have less radiation safety risk than open-beam devices.

* ‘Benchtop’ devices requires you bring the sample to the analytical device; hand-held devices means you take the device to the sample. Benchtop devices have less radiation safety risk than hand-held devices.

Closed-beam, Fixed X-ray Fluorescence

Table-top or Bench-top Analytical Device

Sample chamber port (where you put your sample

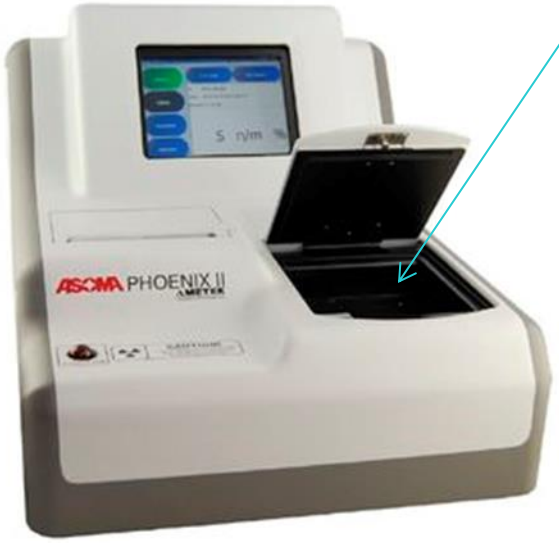
Control panel and display

Put your sample in the sample chamber, close the lid and initiate testing.

This is a closed-beam system. The lid is interlocked, meaning when you open the lid, the device stops producing x-rays. Relatively low risk. This type of device has been around a long time. Note that here, you bring the sample to the analytical device.

There are many shapes and sizes of fixed or benchtop closed-beam analytical x-ray fluorescence devices. Many are made for specific applications.

Enclosed Sample Chamber

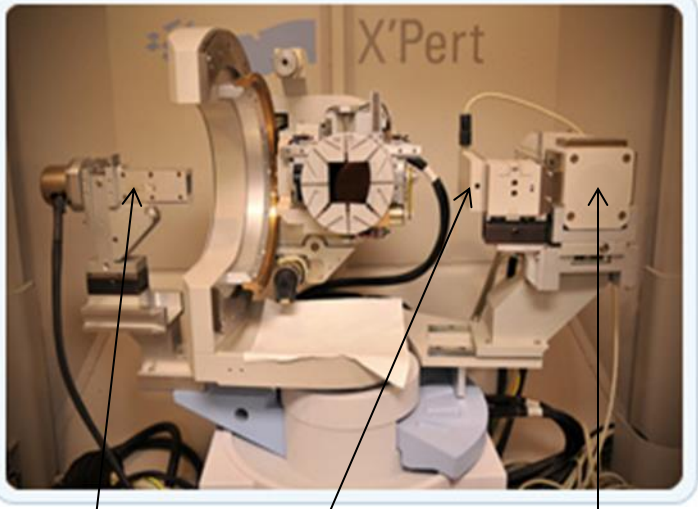


Many devices can hold and test several samples

Multiple Samples

Open-Beam Analytical

This is a bench-top analytical system (using diffraction). It is also an **open-beam** device. Notice you could put your hand in the primary beam. Fixed fluorescence devices are usually not open-beam.



X-ray Fluorescence
Open-beam, Hand-held, Analytical

X-ray Port

Trigger to
Initiate X-rays

Control Panel
and Display

Innov-X Omega (Olympus)

- Energy range between 10 and 50 kV
- Very narrow beam
- Must be very close to the sample *
- Price $20,000 - $40,000

Oxford X-MET 300TX

* **Relatively low or 'weak' x-ray energy.**

Other Manufacturers of Hand-held Analytical Devices

Bruker Titan ↑

Control Panel and Display

Thermo Scientific Niton XL3t ↑

X-ray Port and Detector Port

Spectro xSORT

G.E. XL-PMI

Hand-held X-ray Fluorescence in Use

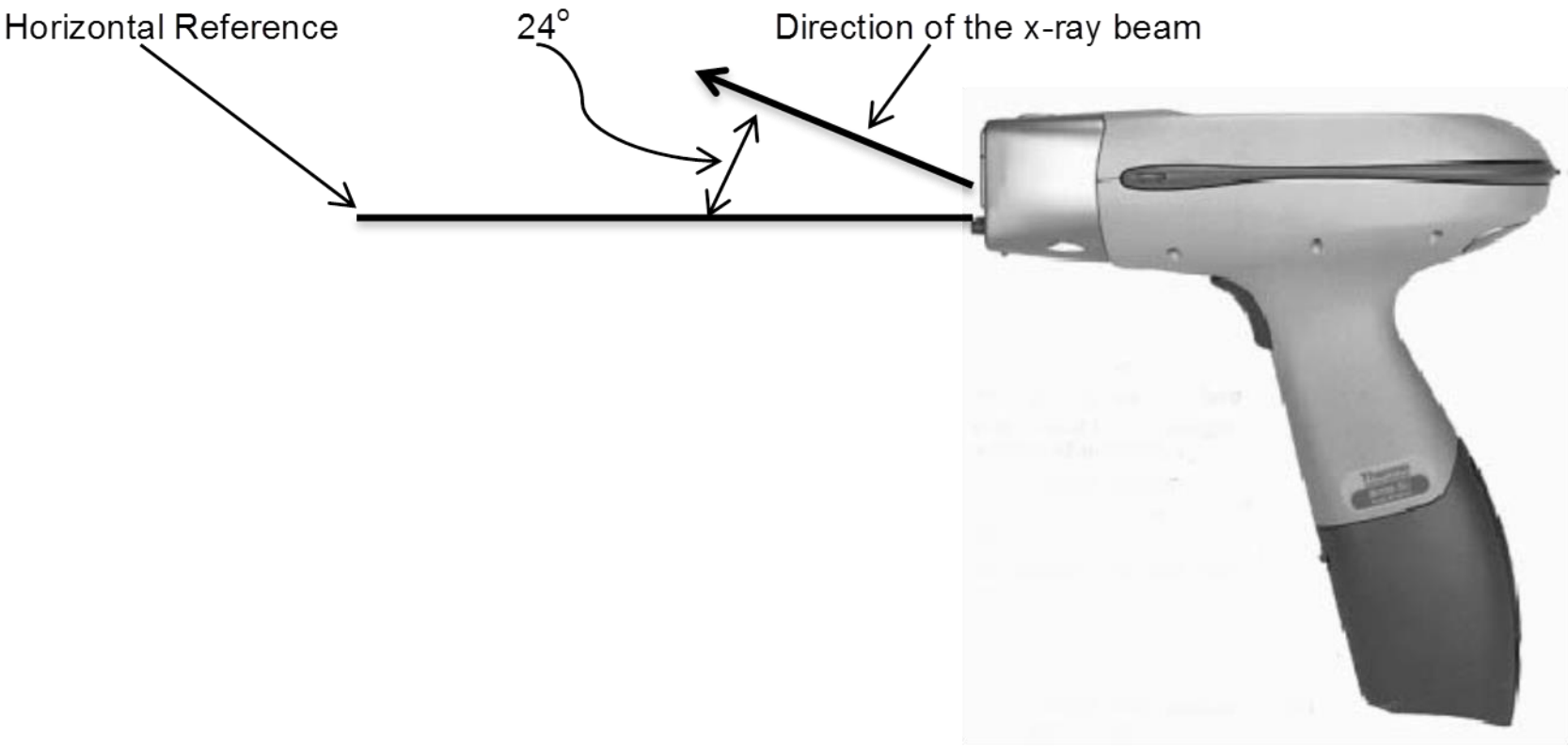
Hand-held X-ray Fluorescence

- Each device is limited in the elements it can identify by the energies it detectable; this is known as the device's 'library'. This is true for fixed as well as hand-held devices.
- Sometimes, manufactures sell devices with only one detectable element, meaning the device is made for one application.
- Example, an importer of children's toys may want only to know if the toy had lead in it.
- A scrap yard would want a large library of identifiable elements.
- You can guess which one is more expensive!

The Purpose of the Hand-held Device

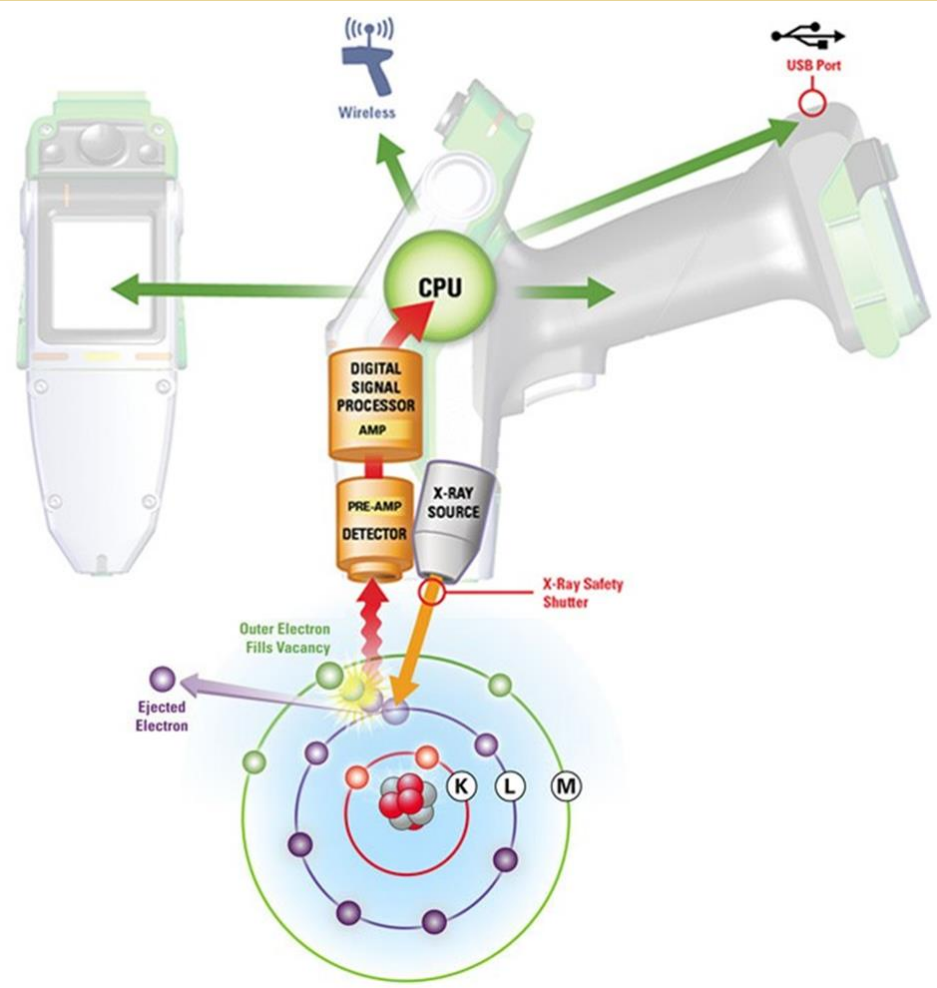
The great advantage of the portable, hand-held x-ray devices is that it allows you to test large objects that cannot be brought to the lab.

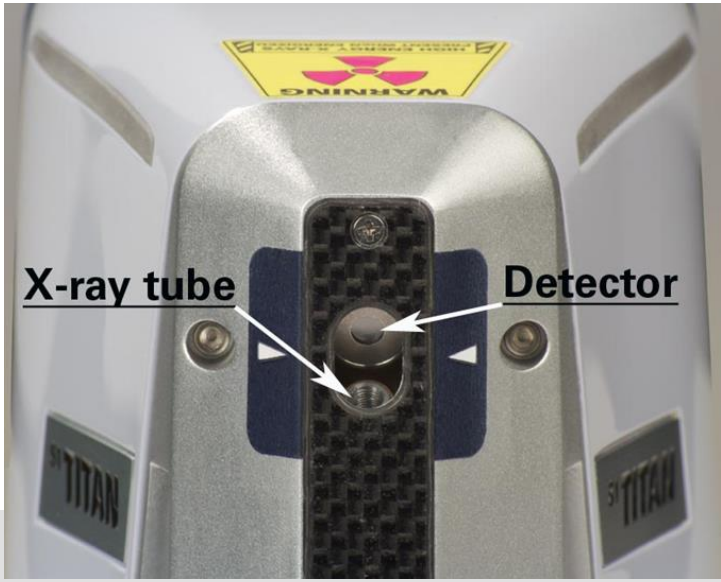
How They Work



Note that the x-ray beam does not come out in a horizontal plane.

How They Work

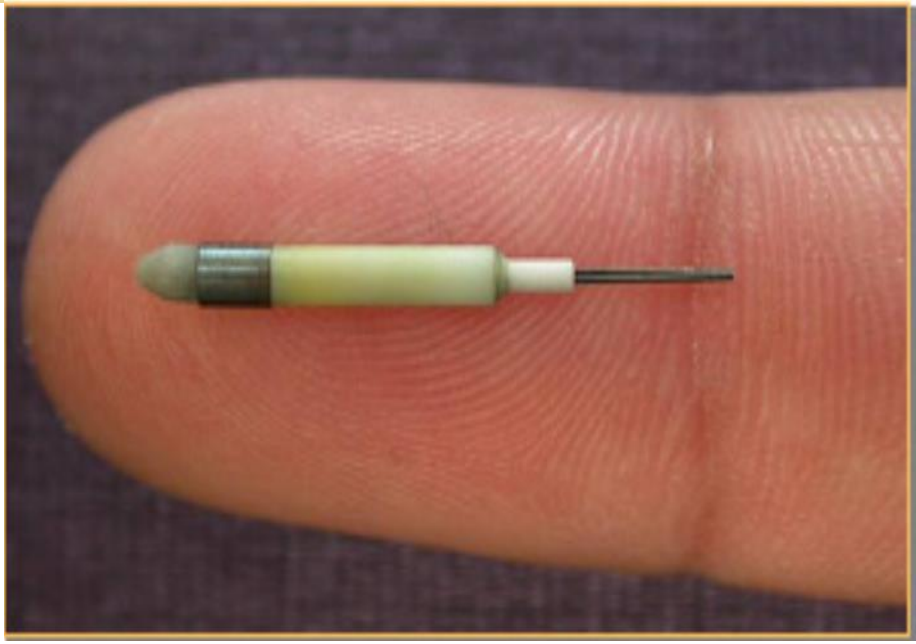




https://www.thermoscientific.com/en/about-us/general-landing-page/xrf-technology.html

How Small Can You Go?

Type of x-ray tube housing found in the hand-held analytical x-ray devices



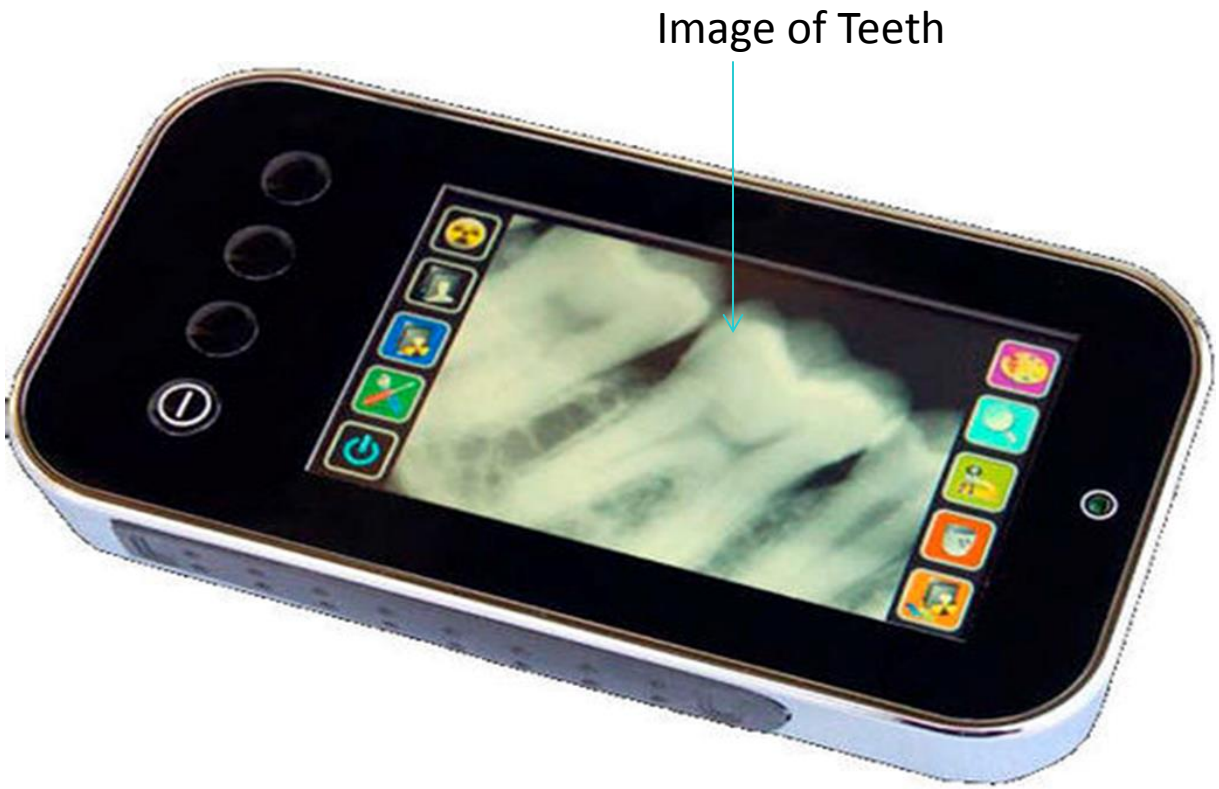
Axxent® Electronic Brachytherapy System® (Xoft, Inc. manufacturer)

50 kV x-ray source

Assembly diameter = 5.4 mm **(2/10”)**
Tube diameter = 2.25 mm **(1/10”)**

Nominal dose rate: 0.6 Gy/min (60 rad) at 3.0 cm in water

How Small Can You Go?



About the size of a smart phone

From a Regulatory Standpoint

- For decades, fixed fluorescence devices were the only way to perform analytical work; holding an x-ray device in your hand was not only against all safety concepts, it was inconceivable how you would do it.

- Over the years, technology in general gets smaller, for example, computers or cell phones; this goes for x-ray tubes and CPUs. With smallness comes the flexibility to do new things, like make an x-ray analytical device small enough that you can carry in your hand.

- Hand-held devices are relatively new to the industry (@ 10 years).

- They are designed to go out into the field to perform testing.

From a Regulatory Standpoint

Regulations require that when using an analytical x-ray device, you must have a **'beam-trap'** or something to intercept and/or attenuate the primary beam. Because of the way these hand-held devices are used, it is not possible to have a fixed, beam trap (e.g., testing very large objects.)

Therefore, as soon as these x-ray devices are purchased, they are out of compliance with state regulations!

FROM A REGULATORY STANDPOINT

- To use the device, users must get an exemption from the regulatory standard.
- Since the hand-held device does not have a physical beam-trap (an *engineered control*), we ask users to institute a procedure (an *administrative control*) on the safe operation of the device that will take into account the lack of the beam-trap safety feature.
- The operators of the x-ray device will then need to be trained on this procedure.

FROM A REGULATORY STANDPOINT

Another regulatory problem with hand-held analytical x-ray devices:

The regulations require that all analytical x-ray devices have an "X-ray On" **warning light** that lights when x-rays are being produced and that this warning light be of a **fail-safe** design. "Fail-safe" means that if the light does not work, the device will not produce x-rays.

These devices typically have LED lights rather than incandescent lights. For some reason, it seems that this LED system cannot be made fail-safe in the traditional way. Manufacturers usually install multiple warning lights to compensate for the lack of the fail-safe safety feature.

Again, we ask that in lieu of the fail-safe light safety feature (an engineering control) that procedures be instituted (an administrative control) that will take into account the lack of the fail-safe safety feature.

Portable XRF Devices Used with Test Stands

Innov-X Device with Test Stand

These would be now considered **closed-beam**. Note that each device now has a primary barrier or a beam-trap. This means the devices are much safer to operate. When used like this, the device is in essence a fixed or bench-top unit.

Bruker Device with Test Stand

Primary Barrier

Sample Chamber

Niton Test Stand (without x-ray device)

Hand-held Analytical Fluorescence Using Radioactive Material

- Before x-ray technology could get an x-ray tube and a detector small enough to put into a portable device, analytical fluorescence performed in the field was done with radioactive material. The device looked very similar to the current x-ray analytical devices.
- Cadmium 103 was the radioactive material used.
- The use of cadmium was limited in the number of samples (metals) it could detect because of the single energy emitted by the radioisotope.
- X-ray technologies allows for a wide range of energies used to create the fluorescence effect.

- Other types of x-ray devices that are coming on the market.

X-ray Devices Used For Security

OpenVision Model X-ray Unit Manufactured by Envision

X-ray Devices Used For Security

MINI Z SCANNER SPECIFICATIONS

Length: 11.5 in (29.2 cm)

Width: 9.8 in (24.9 cm)

Height: 7.6 in (19.3 cm)

Weight: 9 lbs (4 kg)

Operating Time: 4 hrs per battery charge

Scan Speed: 6 in (15 cm) per second

American Science and Engineering (AS&E)

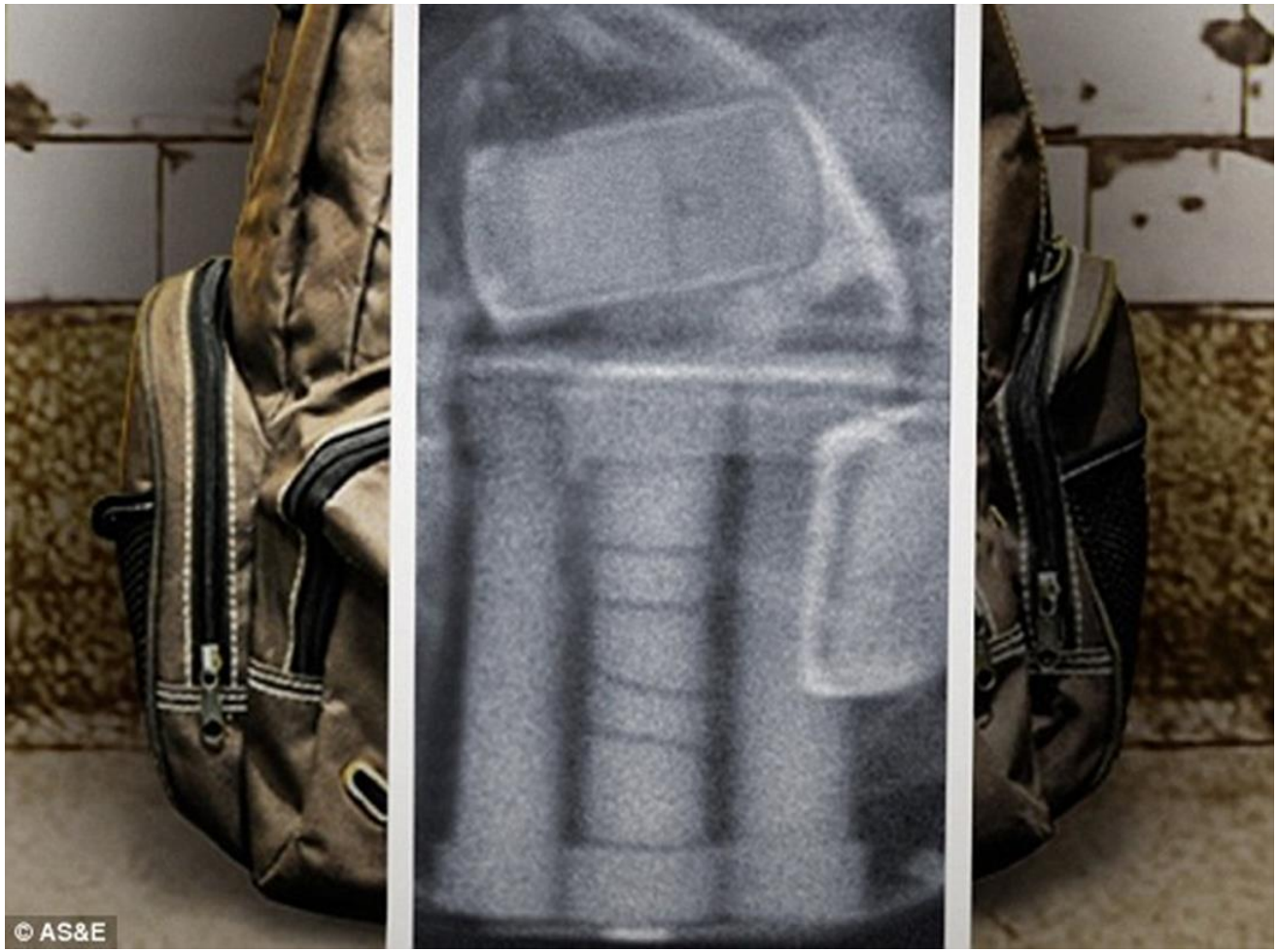
Mini Z

($50,000)

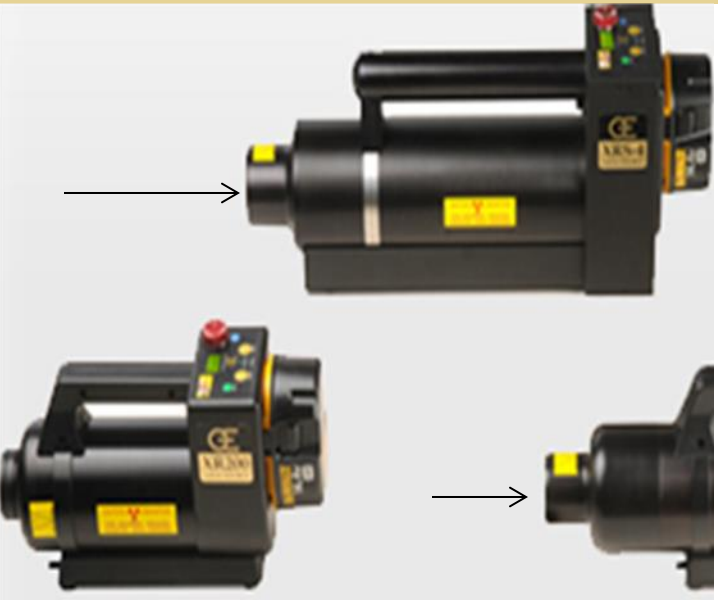
Meet the world's first handheld Z Backscatter imaging system

X-ray Devices Used For Security

What an image looks like from the hand-held backscatter device



X-ray Devices Used for Bomb Squad Detection



X-ray Port Openings

Bomb squads for county and city governments use these particular devices. These devices generate pictures with an image receptor. The deputy puts an image receptor behind the object (film or digital detector), puts the x-ray devices in front of the object, retreats to a safe distance, and generates a static image (not real-time images like fluoroscopy). From that image, hopefully they can determine if there is a bomb inside.

The image on the left are examples of Golden Engineering brand bomb disposal x-ray units.

X-ray Devices Used in Personal Security Screening Systems

Personnel Security Screening Devices

Currently, there are two different types of whole body security scanners; **backscatter** and **transmission.**

The backscatter device emits low energy x-rays that bounce off of the subject being scanned and creates an image. Some of the x-rays will penetrate the body, but not pass all the way through. Therefore, the backscatter device will only image one side of the subject per exposure.

The transmission device emits higher energy x-rays to produce a much more detailed image of the subject. The x-rays from the transmission device penetrate the body. Therefore, the transmission device can image both sides of the body in one exposure.

Transmission devices provide a much greater dose to the subject.

Backscatter, Whole-body, Personnel Screening Devices

The x-ray tube moves up and down the length of the subject's body during exposure.

Imaging one side of the body at a time. This subject will have to turn around and take a second scan to image the entire body. Two scans (exposures) but one screening

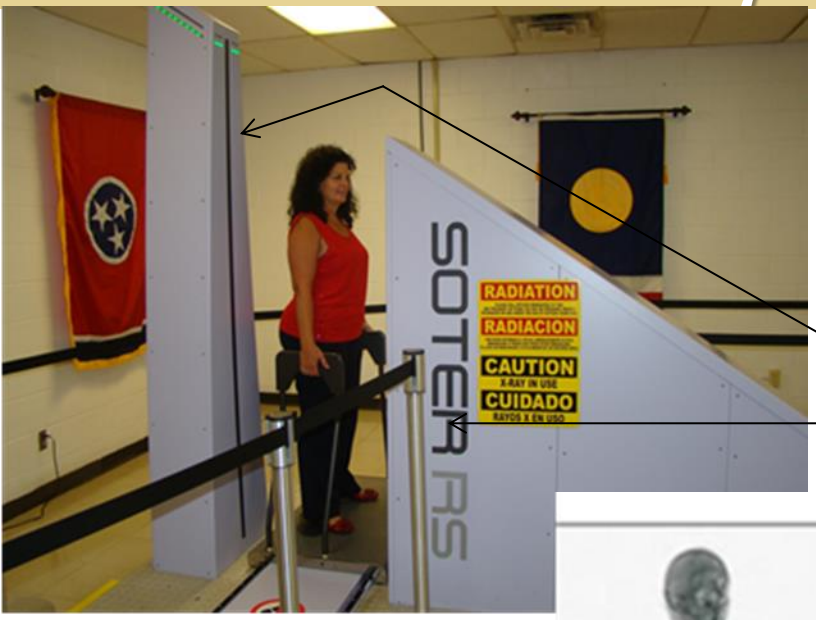
Imaging two sides of the body at a time. To do this, there must be x-rays coming at the subject from both sides; two scans (exposures) but one screening.

Backscatter Image

This is a **backscatter** image. Note that it only images one side of the subject. To get a total view of the subject will take two shots, as in this example.

The TSA stopped using backscatter x-ray devices because of the graphic nature of the images.

Transmission, whole-body, personnel security scanning system



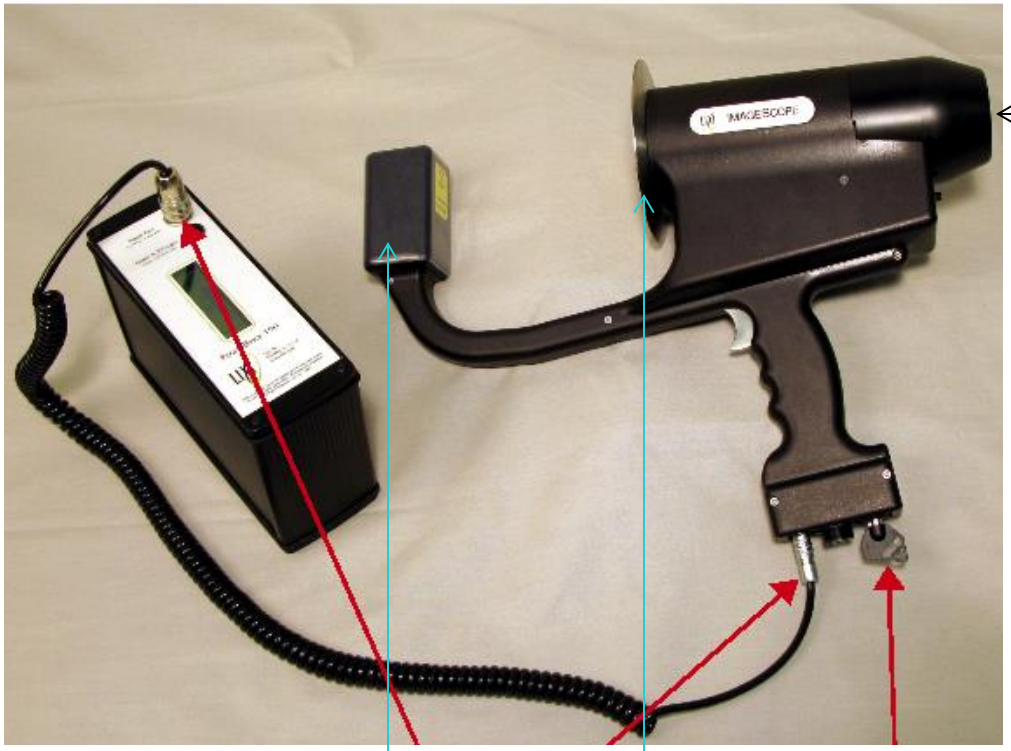
Transmission systems have higher energy x-rays that can penetrate the body and the subject receives more radiation dose. Both sides of the subject are imaged with one scan. One scan (exposure), one screening.

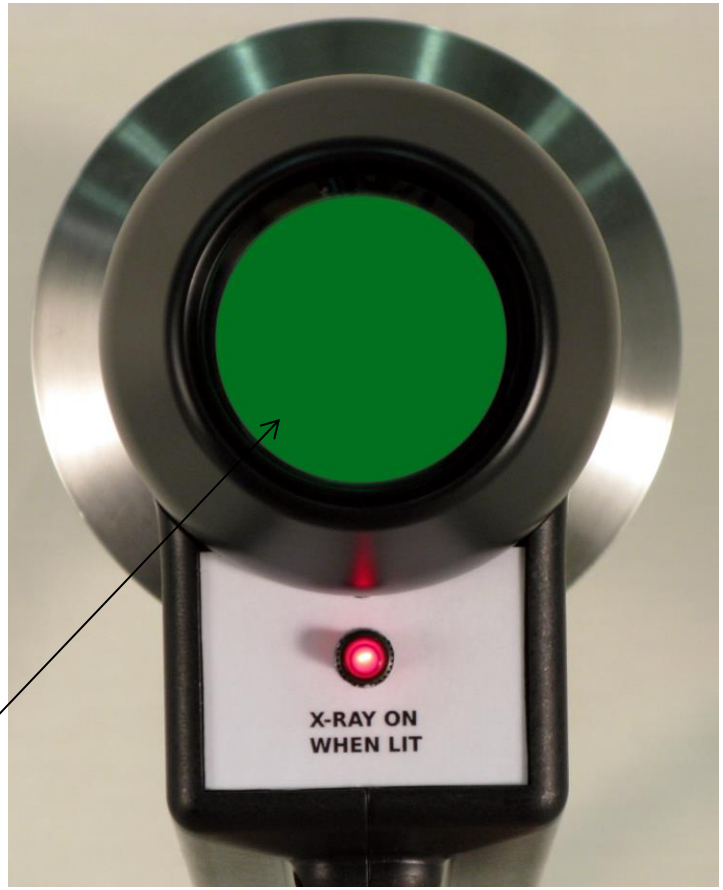
Detector

Tube Housing

Notice in the image to the right that you can see the subject's bones.

Lixi Scope (model ImageScope) – Hand-held





Viewing Screen

Originally designed for imaging children's extremities. Now used by chicken farmers!