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Portable X-Ray Fluorescence-A Versatile Tool for Analysis

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Abstract

The elemental analysis technique known as portable XRF spectrometer, or pXRF, is a rapid, affordable, non-destructive, and sustainable method to assess the elements in a variety of liquid and solid samples. Since food samples are easy to evaluate, rapid, simple, and accurate, it is desirable and promising to utilize pXRF to detect and fingerprint components in food products. We emphasized on reading the literature and making careful assessments of analytical elements such as linearity, LOD, LOQ, calibration methods, and the pXRF instrument's working mode. This accurate analysis, which upholds the status of p XRF in food elemental evaluation, offers food toxicologists enlightening opportunities and inspiration. With the aim to increase the fineness and reliability of upcoming food research, we present methods in this work for using p XRF for in real time evaluation of multiple food specimens (solid and liquid). There is also a review of popular p XRF spectrometers and a discussion of analytical calibration methods that are effective for p XRF studies in food analysis.

Keywords
Environmental analysis, Handheld XRF, Portable XRF, Portable x-ray diffractometer, X-ray fluorescence.

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INTRODUCTION

The important non-destructive analysis technique known as XRF (X-ray fluorescence) fluorescence is used in archaeometry to ascertain the chemical composition of art pieces, metallic alloys, and other interesting materials. It is often not feasible to transport art pieces for analysis in scientific facilities. As a result, there is strong argument for the development of XRF spectroscopy-based portable equipment for measurements "on the field."

General high-resolution cryogenic detectors, like Si (Li) and HPG e sensors (whose accuracy is of a range of 140 ev FWHM at 6 kev), are not utterly appropriate for portable instrumentation in archaeometry. The main barriers stem from the need for liquid nitrogen cooling, which entails the cryostat's substantial dimensions, a need for regular liquid nitrogen replacements, and the cost of maintenance.

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Non-cryogenic detectors, such as Peltier cooled Silicon PIN diodes, have been employed in portable XRF analysis systems due to recent advancements in apparatus size and weight [2]. There are situations even now when their energy resolution, which is roughly 250 ev FWHM at 6 kev, is inappropriate.

Here Our XRF spectrometer rides on an entirely novel type of electromagnetically dispersive detector called the Silicon Drift Detector (SDD). The SDD can attain a resolution of about 160 ev FWHM, or at 6 kev when it gets cooled by a Peltier element. This characteristic makes the electronic gadget ideal for high-resolution images portable XRF spectrometers.

Basics of xrf

In XRF, x-rays generated by a source irradiate the sample. A synchrotron or radioactive material can potentially serve as the source, though x-ray tubes are the most common type. The discrete energy of the fluorescent x-ray radiation released by the elements in a sample is characteristic of that element and is like the colors of optical light. Different energies are associated with different colors. The energy (or colors) of the radiation that the sample emits can be measured to identify the elements that are present. We refer to this stage as qualitative analysis. The amounts of each element contained in the sample can be ascertained by measuring the colours or intensities of the emitted radiation. We refer to this stage as quantitative analysis.

What are x-rays:

X-rays can be thought of as beams of photons with specific energy or as electromagnetic waves with their corresponding wavelengths. Both viewpoints are legitimate, but one is easier to understand will depend on the underlying issue requiring to be explained. Other electromagnetic waves include radio waves, light, and γ-rays. X-rays have energies and wavelengths in between γ-rays and infra violet light, X-rays have wavelengths between 0.01 and 10 nm and an energy range of 0.125 to 125 kev. According to the equation $E*\lambda=hc$, an X-ray's energy and wavelength are inversely correlated. where E is the amount of energy in keV and λ is the length of wavelength in nm.

The constant number of hc, which is the combination of Planck's constant and the acceleration of light, is 1.23985 using kev and nm as units.

History of x-rays: The first-ever Nobel Prize in Physics was given to German mechanical engineer and physicist Wilhelm Conrad Rontgen in 1901 for his discovery and production of electromagnetic radiation on November 8, 1895, in a wavelength range known as X-rays or Rontgen rays.

Though he is not regarded as the first to have seen and felt their effects German physicist Wilhelm Röntgen is typically given credit for the discovery of X-rays in 1895 since he was the very first to conduct a thorough investigation into them.

By examining the cathode rays, or intense electron beams, that were initially generated in the tubes, scientists discovered that they were coming from Crookes tubes, experimental discharge tubes that were created approximately 1875.

Interaction of x-rays with matter

Three main processes are involved when X-rays interact with matter: fluorescence, Compton scatter, and Rayleigh scatter. Some X-ray photons aimed at a slab of material will be deflected back, while other photons will pass through and produce fluorescent light. Scattering can result in both an energy gain and a loss. The first is called the Compton scatter, and the second, the Rayleigh scatter.

The energy of the X-rays as well as the composition, thickness (d), and density (ρ) of the material all affect the scatter and fluorescence. The following sections will address the production of fluorescence radiation and scatter.

Production of x-rays:

Electrons produced: thermionic emission.

The cathode filament warms up and emits ions through thermionic emission when a current is passed across it. A tube voltage placed across the tube accelerates the electrons towards the positive anode. Just one percent (%) of the electron's energy is transformed into x-ray photons at the anode; the rest of the 99% is transformed into heat.

The voltage that is supplied across the tube to quicken the electrons' anode crossing and produce a negative regarded positive gradient is referred to as the "accelerating potential". For radiography, the conventional ranges are 50–150 kV, for mammography, 25–40 kV, and for fluoroscopy, 40–110 kV. Alternating current at 230 V and 50 Hz powers the UK mains supply.

The accelerated potential is reversed, and the cathode becomes positive while the anode becomes negative when the electrical charge is negative. An x-ray beam is not produced by accelerating the electrons towards the anode. A positively charged persistent squared wave, in which the charged particle flow is continually directed towards the anode, is the optimal waveform for imaging.

The voltage that is supplied across the tube to quicken the electrons' anode crossing and produce an opposite to positive gradient is referred to as the "accelerating potential". For radiography, the conventional ranges are 50–150 kV, for mammography, 25–40 kV, and for fluoroscopy, 40–110 kV. Alternating current at 230 V and 50 Hz powers the UK mains supply. The accelerated potential is reversed when the electrical charge is negative, making the anode negative and the cathode positive. To create an x-ray beam, the charged particles are not propelled towards the anode. A positively constant square wave with steady electron flow towards the anode is the best waveform for imaging. continuously.

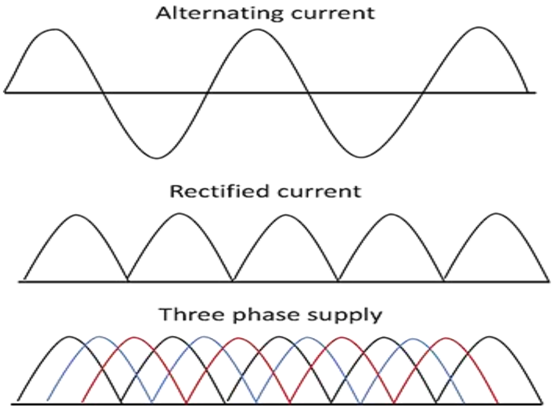


Figure 1

x-ray production at the anode

Very rarely does elastic contact occur until kvp is greater than 10 eV. At the highest velocity of kvp, electrons release energy via attaching to the surface of the anode. When electrons come into contact, they do not release energy. Atoms are stimulated or ionized by inelastic contact, which releases heat energy and electromagnetic radiation (EM). Connections X-ray photons at the anode can be produced by a variety of interactions between the anode's atoms and electrons. Interaction with the outer shell: Quick conversion of low-energy electromagnetic radiation to heat energy occurs. Inner shell interaction generates distinctive radiation Bremsstrahlung is another term for atomic force interaction.

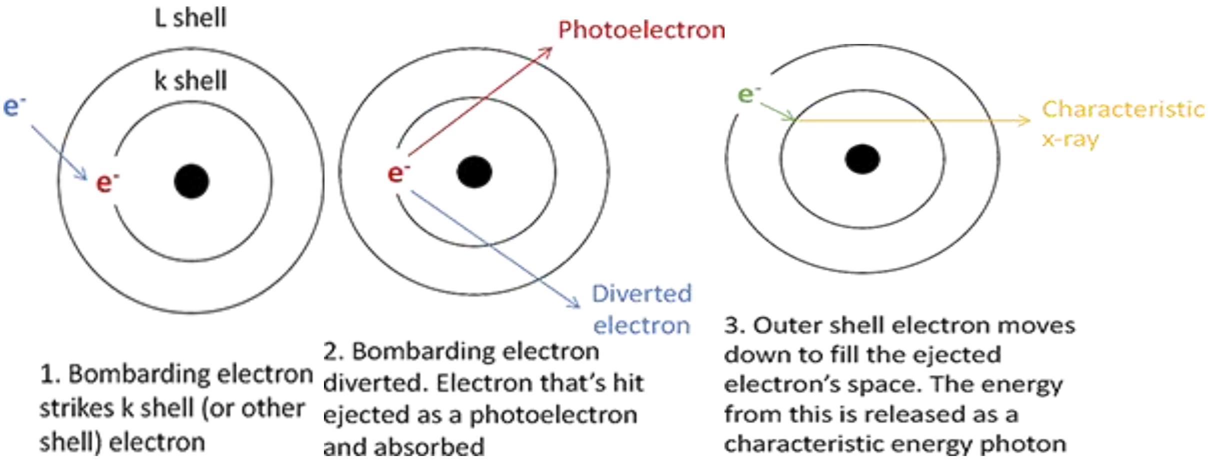
characteristic radiation

An electron in the bombardment shell removes an electron in the k- or l-shell.

An electron via a higher shell hits the open zone.

An x-ray photon is the energy released during this transition to lower levels of energy.

The bombarding electron gets deflected but keeps going in the same direction.



1. Bombarding electron strikes k shell (or other shell) electron

2. Bombarding electron diverted. Electron that's hit ejected as a photoelectron and absorbed

3. Outer shell electron moves down to fill the ejected electron's space. The energy from this is released as a characteristic energy photon

It can also be referred to as "characteristic" because the kinetic energy of the released electrons has distinct ranges that correspond to the repulsive forces of various shells and are determined by the anode's material instead of the tube voltage.

Bremsstrahlung

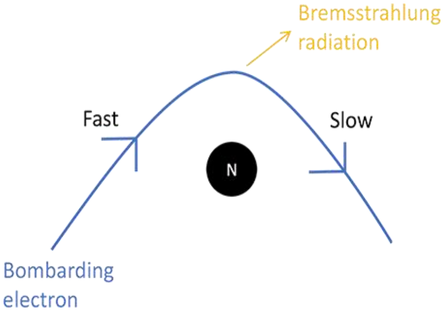


Figure 2: Bremsstrahlung Radiation.

An electron is blasted as it gets closer to the nucleus. Electrons are deflected by the nucleus's electric field. This diversion results in the loss of energy and the release of photons, also known as bremsstrahlung radiation. Bremsstrahlung causes a spectrum of photon intensities to be released. Eighty percent of x-rays are produced by the bremsstrahlung method. An electron will sometimes completely halt and release all its energy as a photon. More often, a series of actions taken place where the electron progressively loses energy.

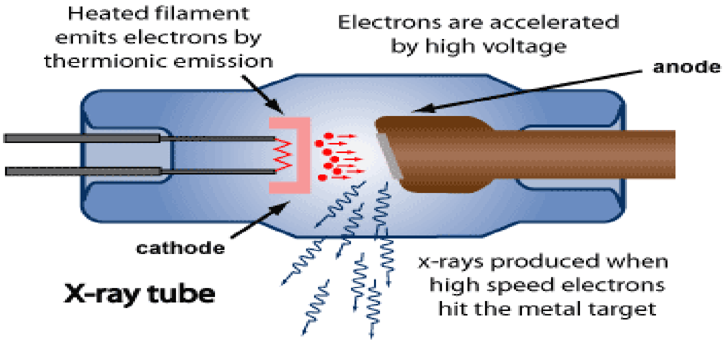


Figure 3: Production of X-Rays.

What is portable xrf:
With the pxrf (portable XRF) spectrometer, elemental analysis is quick, inexpensive, environmentally friendly, and non-destructive for a variety of sample kinds (solid or liquid).

Given that food samples have a low persistence and are quick, easy, and precise to analyze, using pxrf to identify and fingerprint components in food products is a desirable and promising approach.

We concentrated on evaluating the existing research, paying particular attention to analytical elements such as linearity, LOD, LOQ, calibration techniques, and the pxrf device's working mode.

Ways to enhance the caliber and dependability of upcoming food studies employing pxrf for the on-site examination of several food kinds (liquid and solid).

The analytical method known as portable X-ray fluorescence (pxrf) allows for quick and non-destructive elemental examination of materials. It operates by subjecting a sample to X-ray radiation, which results in the sample's atoms emitting distinctive X-ray fluorescence. The elements and their quantities in the sample are then ascertained by detecting and analyzing the X-rays that are released.

For in situ statistically elemental studies in a variety of kinds of samples, particularly liquid and solid ones, the portable XRF method—also sometimes referred to as the field-portable XRF (FP-XRF) or handheld pxrf technique—is a highly helpful analytical instrument that is frequently overlooked.

There are several advantages to this technique: it is fast, non-destructive, and can be utilized for in situ evaluation (portable device). one accurate measurement in approximately one minute, and affordability (specific measuring cups are the only requirement for powdered and liquid samples).

History of portable xrf:

The evolution of X-ray fluorescence analysis itself is intimately linked to the history of portable X-ray fluorescence (pxrf) spectrometry.

The discovery of fluorescence x-ray (xrf):

Sir William Crookes made the initial discovery of X-ray fluorescence in 1869. He noticed that some materials released secondary X-rays with distinct energy when they were subjected to X-rays.

Early XRF Spectrometers: Designed for use in laboratories, the first XRF spectrometers were created in the early 1900s. These were heavy instruments that needed a consistent power supply.

1990s: Commercialization of Portable XRF: During this decade, the first pxrf instruments were made available for purchase. These early models were frequently applied to certain fields, such metal analysis and mining.

21st century: innovations and expanded uses.

The development of pxrf technology persisted in the 2000s and 2010s. Instruments got smaller, easier to operate, and could analyze more different kinds of data.

The application of this technology spread to several disciplines, such as environmental science, art conservation, archaeology, and more.

Current Status - Wide Range of Applications: Because of its adaptability, speed, and non-destructive nature, portable X-ray fluorescence (pxrf) spectrometers are now widely employed in industry, research, and field applications.

Producers are keeping up the innovation, providing pxrf equipment that are more advanced and easier to operate.

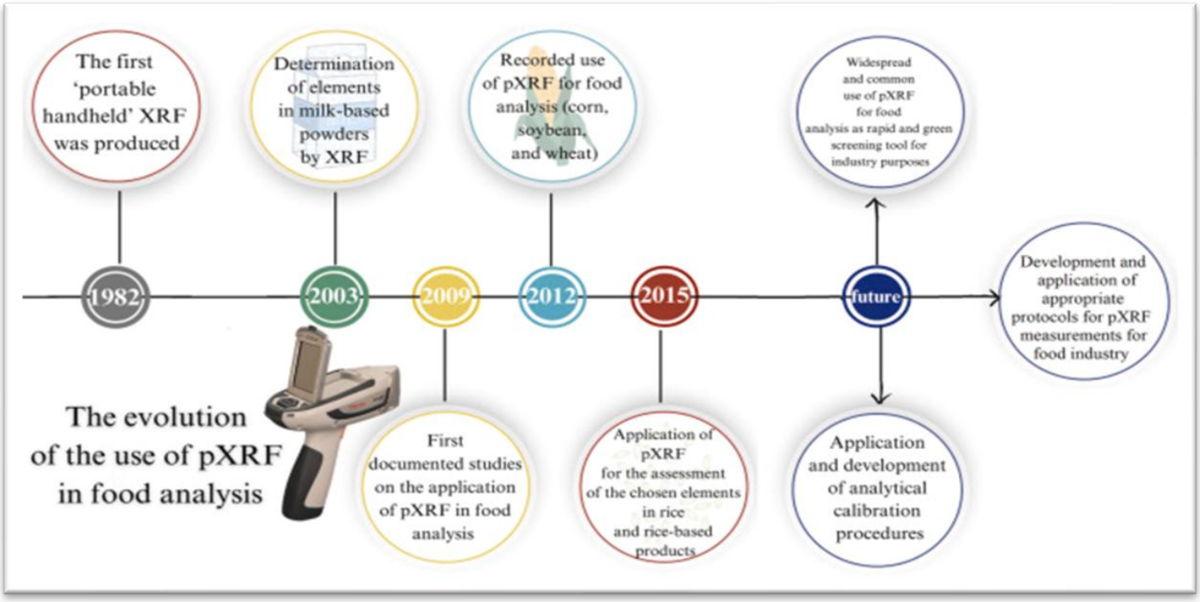


Figure 4: Evolution of pXRF

Principle of portable XRF:

One analytical method that provides details on a sample's elemental makeup is X-ray fluorescence. When an X-ray beam is directed towards a sample, the atoms it strikes produce X-rays back, often at a variety of energies. The distribution of X-rays emitted by different elements varies, therefore the elements contained in a sample can be determined by looking at the X-ray spectrum.

The amount of energy dispersive X-ray fluorescence analyzers found in laboratories and portable XRF analyzers operate on the same concept. Lately, they have benefited from developments in the miniaturization of components to provide portable, light, and compact devices. The working idea is that when X-rays from a source of excitation interact with a test surface, fluorescent X-rays with energy typical of the stimulated material's molecules are produced. The two configurations of radioactive isotope sources of excitation (55Fe, 109Cd, and 241Am) used in specific devices. These days, it's usual to use tiny X-ray tubes that barely draw a few watts.

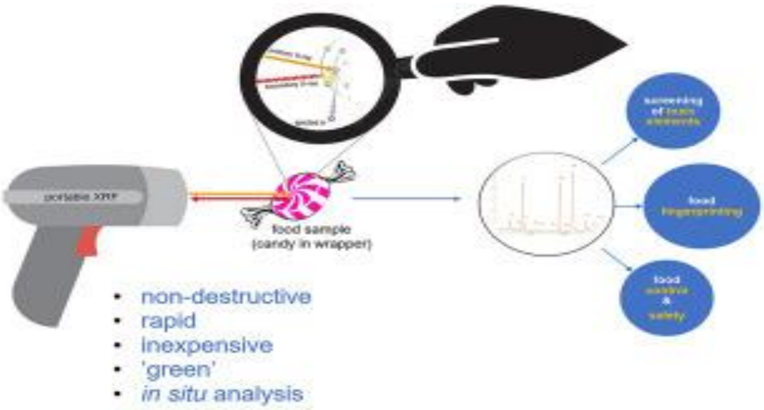


Figure 5: Principle of Portable XRF

INSTRUMENTATION:

Analytical tools called portable fluorescence X-ray (pXRF) instruments are used to analyze different materials' elements on-site. They are frequently used in environmental science, mining, geology, archaeological research, and materials testing [3].

These are the major components and features of the portable XRF's instrumentation:

x-ray source:

In pXRF equipment, an X-ray tube typically serves as the X-ray source. This source produces X-rays when electrons with a high energy collide with a substance that is metallic target, usually made of rhodium or silver. The material being targeted selection affects the spectrum of energy of the X-rays generated, which determines which elements can be recognized.

X-ray detector: High purity silicon is used to manufacture the silicon drift detector (SDD) sensor, which has extensive contact on the entrance side that faces the incoming X-rays. A small, central anode contact on the other side is encircled by several concentric drift electrodes. The SDD detector chip turns each X-ray observed into a cloud of electrons with a charge proportionate to the distinctive energy of the individual X-ray when a bias is added to it and the detector is subjected to X-rays. These electrons rise into the silicon semiconductor's conduction band, leaving behind holes in the sensor that act like free positive charges. After that, a field gradient is provided between the migrate rings to "drift" the electrons down it [4].

Collimator:

The X-ray beam's departure is limited by a collimator, which improves spatial resolution and shields the beam from nearby interference.

Filters:

The X-ray spectra can be altered by filters, which can aid to maximize an instrument's performance for components or uses [5].

Sample chamber:

The material is kept safe for analysis in the sample chamber. Its purpose is to facilitate effective X-ray interactions with the substance.

Detector electronics:

The signals that come from the detector are processed by electronics to provide data that may be used for elemental analysis.

User interface:

A display screen and simple controls for entering data and interpreting results are common features of portable XRF devices' user-friendly interfaces.

Battery/power supply:

With its display screen and simple controls for data entry and result interpretation, portable XRF devices usually offer an easy-to-use interface [6].

Data storage and transfer:

pXRF equipment may include options for transmitting information to external devices in addition to internally storing analytical data. Wireless data transfer is also supported by some instruments.

Calibration standards:

To ensure precise elemental analysis, the device is calibrated using calibration standards. Standard calibration curves are supplied by the manufacturer, and users might need to recalibrate the device on a regular basis.

software:

The data is processed by analytical software, which then outputs the elemental composition. It might have functions for reporting, exporting, and interpreting data.

safety features:

Safety measures are built into pXRF equipment to shield users from X-ray exposure. These could consist of safety procedures, interlocks, and shielding [7-9].

durability and portability:

pXRF equipment is made to be robust and portable because they are meant to be used in the field. They might have water resistance, tough casings, and additional outdoor-use features.

It's crucial to remember that distinct pXRF instrument models and manufacturers may differ in terms of certain features and capabilities. To guarantee accurate and secure analysis, users should adhere to the relevant safety recommendations and instrument-specific operating protocols [11-13].

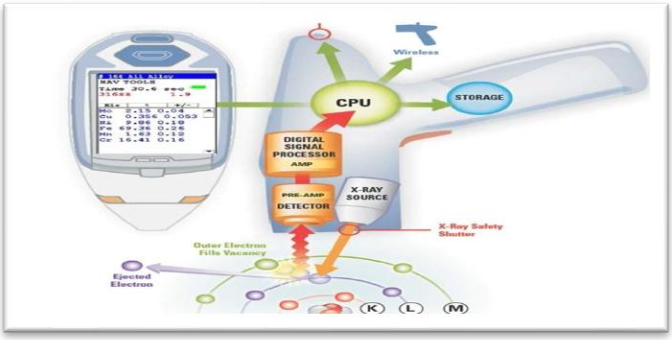


Figure 6 Mechanism of Portable XRF

Figure.7: Handled XRF Metal Analyzer

Safety precautions:

X-ray radiation is only released by the apparatus when a measurement is started by the user. The primary beam exposes users to a significant radiation dosage. The auxiliary (scattered) beam shows a somewhat lower dosage when compared to the primary beam.

Samples with minimal density (plastics, wood, and soil samples) and those that do not completely cover the measuring window receive a higher dose from the secondary beam.

During a measurement, there is a little quantifiable dosage present in the plastic enclosure and handle. If an individual uses the spectrometer for approximately 2000 hours annually and uses the X-ray tube during that span, the regular dosage for those whose jobs don't subject them to radiation does not exceed the limit values.

APPLICATIONS:

Mining exploration:

Gold exploration: To ascertain the level of concentration of mining and other precious elements in rock samples, handheld XRF analysers are frequently employed in gold exploration. These data can be used by mining corporations to determine the economic viability of a specific site. For instance, a mining business in a remote area might rapidly determine the concentration of gold in specimens of rock from a possible mining site by using a portable XRF analyser.

Archaeology:

Artefact Analysis: Portable XRF analysers are used by archaeologists to examine the metal, ceramic, and artefact compositions. To date and validate the artefacts, for example, a team digging a Roman historical site would employ a portable XRF analyser to determine the fundamental makeup of recovered coins.

Environmental science:

Evaluation of Soil Contamination: To evaluate soil contamination, environmental scientists can use portable XRF analysers. For instance, in a study examining the level of pollution from heavy metals in urban gardens, scientists could detect the amounts of materials like lead, cadmium, and arsenic in soil specimens from various garden plots using a portable XRF analyser.

Metals recycling:

Sorting Scrap Metal: Portable XRF analysers are used by metal recycling plants to swiftly sort and identify different kinds of scrap metal. These facilities correctly distinguish valuable metals from non-value ones, cutting waste and raising earnings, by examining the elemental makeup of metal pieces.

Geology:

Mineral exploration: To map geological formations and identify minerals, geologists utilise portable XRF analyzers. Geologists may use a portable XRF analyser to examine rock samples as part of a mineral exploration operation to find commercially valuable rocks like copper, zinc, or elements of rare earths.

Quality control in manufacturing:

Verification of Metal Alloy: Portable XRF analyzers are used by manufacturers to confirm the overall composition of alloys of metal used in a range of goods. A company that manufactures aerospace components, for instance, might utilise a portable XRF analyzer to make sure the alloy used in a crucial part satisfies the necessary requirements.

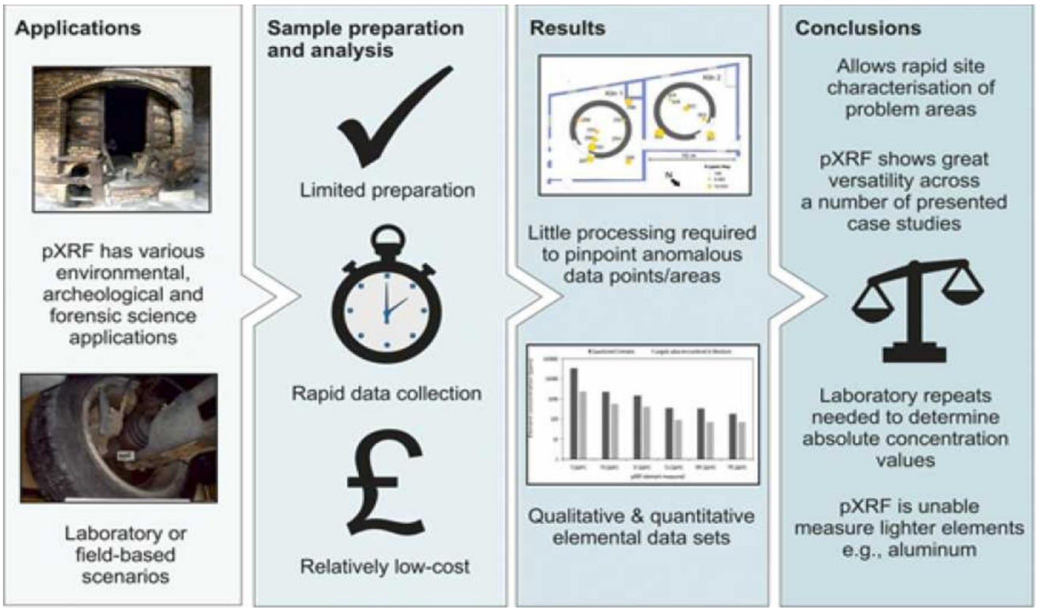


Figure.8 Applications Chart

CONCLUSION:

In a variety of fields and applications, portable X-ray fluorescence (pXRF) technology has shown to be an effective and useful instrument. It is a vital tool for fieldwork, quality assurance, surveillance of the environment, and materials characterisation due to its quick and non-destructive elemental analytical capabilities.

The fact that portable XRF offers a useful and efficient solution for a broad range of industries has significantly influenced fundamental analysis in the field of study. As technology advances, we can expect further improvements in the precision, sensitivity, and scope of the substances that can be evaluated with portable XRF devices, which will make them even more crucial for applications down the road.

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