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To determine radioisotopes and heavy elements with the help of various detectors

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ABSTRACT

Many detectors are used for determining the radioisotopes and heavy elements present on earth. Some of those detectors or methods that are widely used to determine radioisotopes and heavy elements are high-purity germanium (HPGe) detector, sodium iodide (NaI) detector, Geiger Muller counter, atomic absorption spectrometer (AAS), inductively coupled atomic emissions spectrometer (ICP-AES), inductively coupled plasma mass spectroscopy (ICP-MS). These detectors are very sensitive. Theycan detect even trace elements. Radioactive isotopes and heavy elements that may be present in low concentrations can be detected by these sensitive radiation detectors.

KEYWORDS

Radioisotopes, heavy elements,HPGedetector, NaIdetector, G. M. Counter, AAS, ICP-AES,

ICP-MS

1. INTRODUCTION

Every day, people are exposed to ionizing radiation from different sources. These sources are classified as natural or artificial. Natural sources include gamma radiation from Earth, cosmic rays, and many radioisotopes that are naturally present in foods and beverages. Artificial sources include nuclear activities, the release of radioactive waste, medical treatment, etc.Food may be accidentally or deliberately contaminated with chemical or physical substances that should not be present in food. The authentication of agro-food products has become a crucial issue over the past decade as several major food adulteration events were discovered. According to the International Food Safety Authority Network, plants commonly used as food contain ^{238}U, ^{232}Th, and ^{40}K and their progeny [12]. The major route for radionuclide to enter the human body is through the food chain by direct or indirect contamination of natural radionuclide [18]. The composition of human diet varies from person to person and place to place. ^{137}Cs is emitted in nature by nuclear activities, the release of nuclear waste, etc.

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They are transmitted through the roots of plants to their leaves, their flowers and eventually their fruits [1]. Recently, the concentration of many heavy metals in the environment has been increasing due to development activities including industry and agriculture. These heavy metals are very harmful and can accumulate in the soft tissues of animals, plants, and humans when they enter the body. These heavy metals can cause many diseases like skin burns, bone cancer, liver cancer, and leukaemia. Some heavy metals that can cause health problems include copper, lead, nickel, uranium, chromium, iron, zinc etc.These heavy metals can pose a threat to human health and aquatic ecosystems [18]. Food must be tested and analyzed to ensure that the levels of these contaminants are in line with agreed international requirements. Therefore, various detectors are used to identify or determine the concentration of radioisotopes and heavy elements. Some of them are high purity germanium (HPGe) detector**,** sodium iodide(NaI)detector, atomic absorption spectrometer(AAS), atomic emission spectrometer (AES), inductively coupled plasma mass spectrometer(ICP-MS) and GM counter.

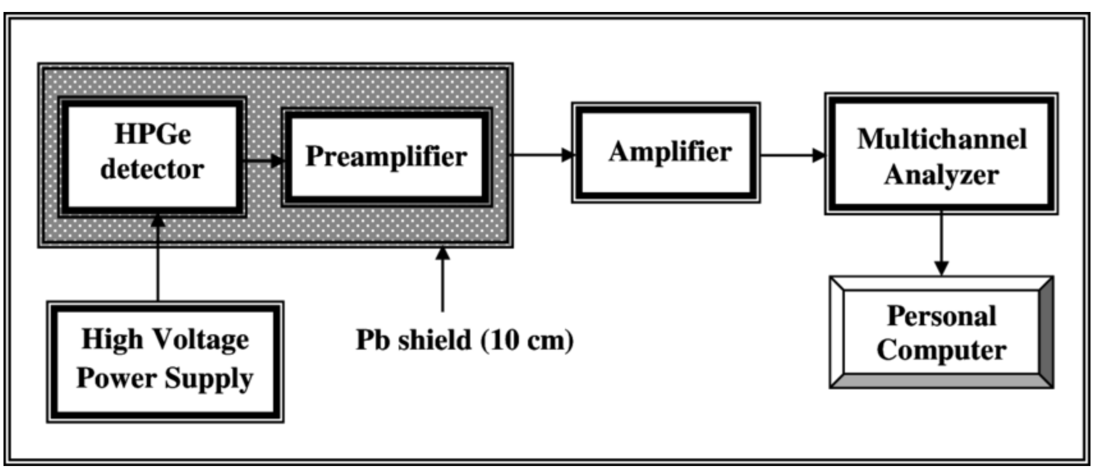
2. High Purity Germanium (HPGe) Detector

The High Purity Germanium (HPGe) detector is a radiation detection technology that provides precise and enough information about radionuclide. Germanium detector have a p–i–n structure, in which the intrinsic (i) region is sensitive to ionizing radiation, especially X-rays and gamma rays. Germanium detector has the supreme resolving power and high photon detection efficiency. To achieve maximum efficiency, the germanium detector must operate at low temperature, because at room temperature, the noise induced by thermal excitation is very high.

2.1Detection system

Firstlyionizing radiation enters the Germanium crystal and interacts with the semiconductor material. After that, the atoms of the semiconductor get ionized and produced the electron-hole pairs. Many electrons are transferred to the conduction band from the valence band.

Fig1: HPGedetector based gamma radiation detection system



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An equal number of holes are created in the valence Band. Germanium absorbs high-energy photons completely. Electron and hole move toward the electrodes under the effect of the electric field and Pulse is recorded. This pulse gives information about the energy of the incident radiation.

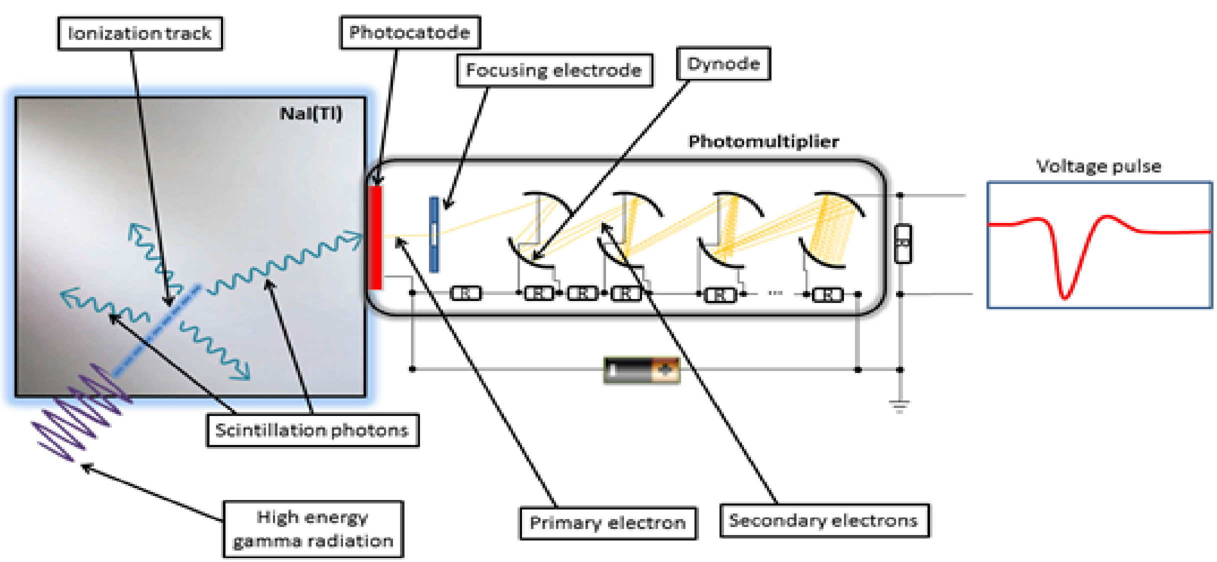
3. Thallium doped sodium iodide NaI (Tl) detector

Sodium iodide detector is used for detecting gamma rays of low and intermediate energies. This is the most widely used detector in nuclear physics, geophysics, and nuclear medicine. This detector gives the best performance and resolution. Its relatively low cost, flexibility in size and linear energy response make Sodium iodide thallium doped NaI (Tl) detector the most widely used detector.

3.1 Detection system

It works on the principle of scintillation. When radiation strikes the scintillator, it emits photons. These photons pass through the crystal and hit a photocathode and light enters the photomultiplier tube (PMT). When photons hit the photocathode, an electron is ejected from the photocathode. Before the photocathode, there is a set of metal cups, each with voltage applied to it. The electron accelerated by this voltage and it hit the cup with enough energy that it emits several other electrons.

Fig 2: illustration of scintillation event in a photomultiplier tube



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Every electron accelerated towards the next metal Cup where each of the new electrons emits many other electrons. Each next stage has a higher potential than the previous to accelerate electrons. At the final dynode, a high number of electrons are present to produce a pulse. This pulse carries information about the energy of the incident ionizing particle. Sodium iodide detector is mainly used for identifying the radioisotope and it also measures their concentration level.

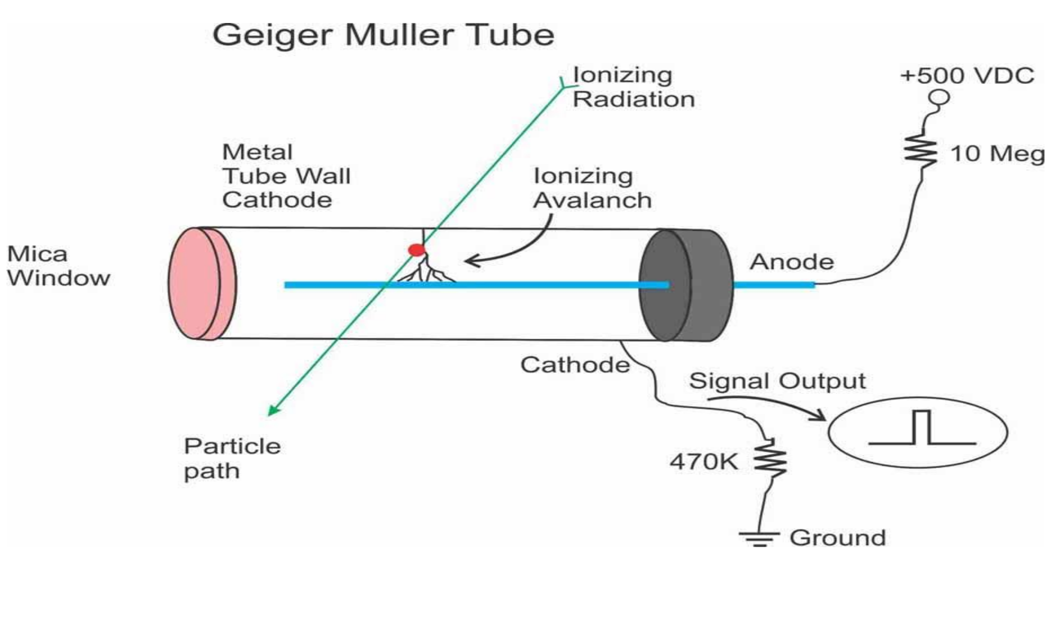
4. Geiger Muller (G.M.) Counter

GM counter is used to detect alpha, beta and gamma rays using the ionization effect produced in a Geiger Muller tube. In 1908, the German physicist Hens WilhelmGeiger introduced the first Geiger detector of individual alpha particles. Later version of this counter was able to count beta particles and other ionizing radiation. Under the circumstance of the very low cost of manufacturing radiation devices, the GM counter was invented.

4.1 Detection system

G.M. counter consists of a Geiger Muller tube and processing electronics that display the result. The tube is filled with a gas i.e.Neon, Helium, or argon at low pressure, to which a high voltage is applied. When a photon of incident radiation makes the gas conductive then the tube conducts an electrical charge. The ionization is amplified in the tube to produce an easily measured detection pulse, which is supplied to the processing and display electronics.

Fig 3: Diagram of Geiger Muller counter



The supplied voltage must be handled with care, as too high a voltage will damage the equipment and invalidate the results. If the voltage is too low the pulse will not be generated. "End window" type Geiger Muller tubes are used for alpha particles and low energy beta particles.In This type of window, one end is covered with thin material through which low-penetrating radiation can easily pass. "Windowless" type GM counterare used for high penetrating radiation detection.This type of tube would not have any windows and the thickness would be in the range of one to two mm.

5. Atomic Absorption Spectrometer (AAS)

Atomic absorption spectrometer (AAS) is a technique in which free atoms absorb energy at a specific wavelength to produce a measurable signal. In 1954, Alan Walsh developed the atomic absorption spectrometer. The main components of Atomic absorption spectrometer are; a light source, atomizer, monochromator, detector and recorder.

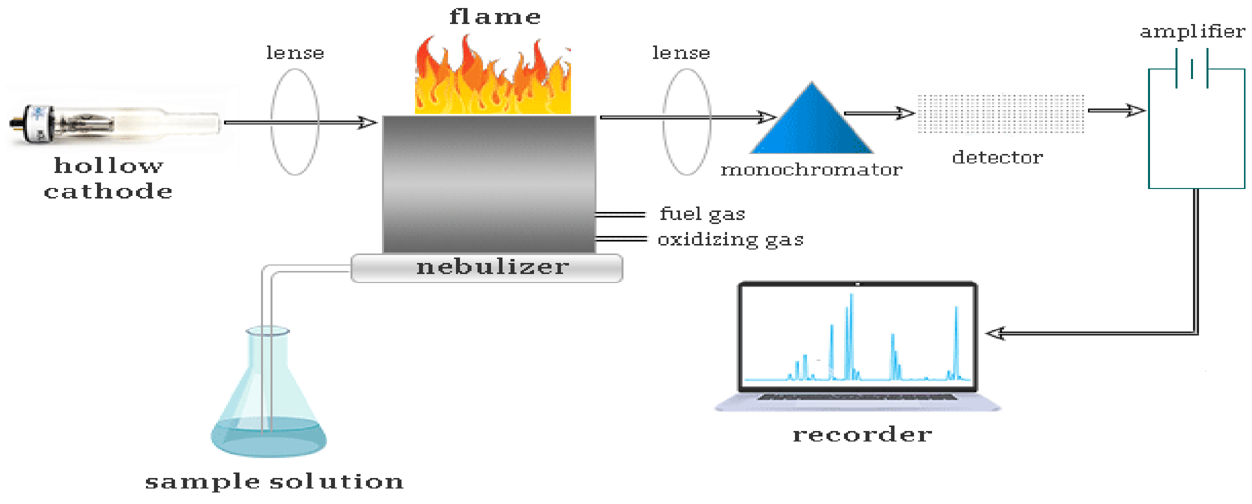
5.1 Light source

The light source provides monochromatic light for the absorption process. Mostly hollow cathode lamps are used as the light source. It consists of an anode of tungsten and a cathode made of an element to be determined. The lamp is filled with an inert gas such as neon or argon.

5.2 Atomizer

The fuel and oxidant gases are filled into a chamber that passes through a baffle to the burner. A flame is produced in AAS. Atomization is done by flame. Heat energy is used to convert metallic elements to atomic vapour. That temperature should be controlled very carefully.

Fig 4: Schematic diagram of atomic absorption spectrometer (AAS)



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5.3 Monochromator

Monochromator produces monochromatic light by removing undesirable wavelengths from the source light beam. This is absorbed by the sample. The picking of specific light allows the determination of the selected element in the presence of others.

5.4 Detector

Detector is used to convert a light signal into an electrical signal. The light selected by the monochromator is directed toward the detector.

5.5 Recorder

After converting the electrical signal, the detector sends those signals to the recorder to convert them into an understandable response. Nowadays, we use a computer system with suitable software for recording signals. A calibration curve is used to determine the unknown concentration of an element.

6. Inductively coupled plasma atomic emission spectroscopy (ICP-AES)

Atomic emission Spectroscopy (AES) is the technique that is used to measure the concentration of elements. It uses the intensity of light emitted from a flame, plasma or Spark at a particular wavelength. Atomic absorption spectroscopy is also known as *inductively coupled plasmaoptical emission Spectroscopy (ICP-OES) or inductively coupled plasma emission spectroscopy (ICP-AES)*. The instrumentation of Atomic emission Spectroscopy is the same as that of the Atomic absorption spectrometer but without the presence of a radiation source. In AES, the sample is atomized and analyse atoms are excited to higher energy levels. In Atomic emission Spectroscopy (AES), AC arc, DC arc, AC spark, DC plasma and inductively coupled plasma are used as a source. Inductively coupled plasma is the most frequently used technique in Atomic emission Spectroscopy.

6.1 Flame

Flame is used for those molecules which do not require very high temperatures for excitation into atoms. The sample is sprayed either as a solution form or directly into the burner flame. Thermal energy excites the atoms then after some time atoms return to the ground state and emit light. Each element emits light of a specific wavelength and then they are detected in the spectrometer.

6.2 Plasma

Plasma is used to excite an atom that emits electromagnetic radiation of a specific wavelength. Mainly three types of Plasma can be used inAtomic emission Spectroscopy (AES). These are; inductively coupled plasma (ICP), directly current plasma (DCP) and microwave-induced

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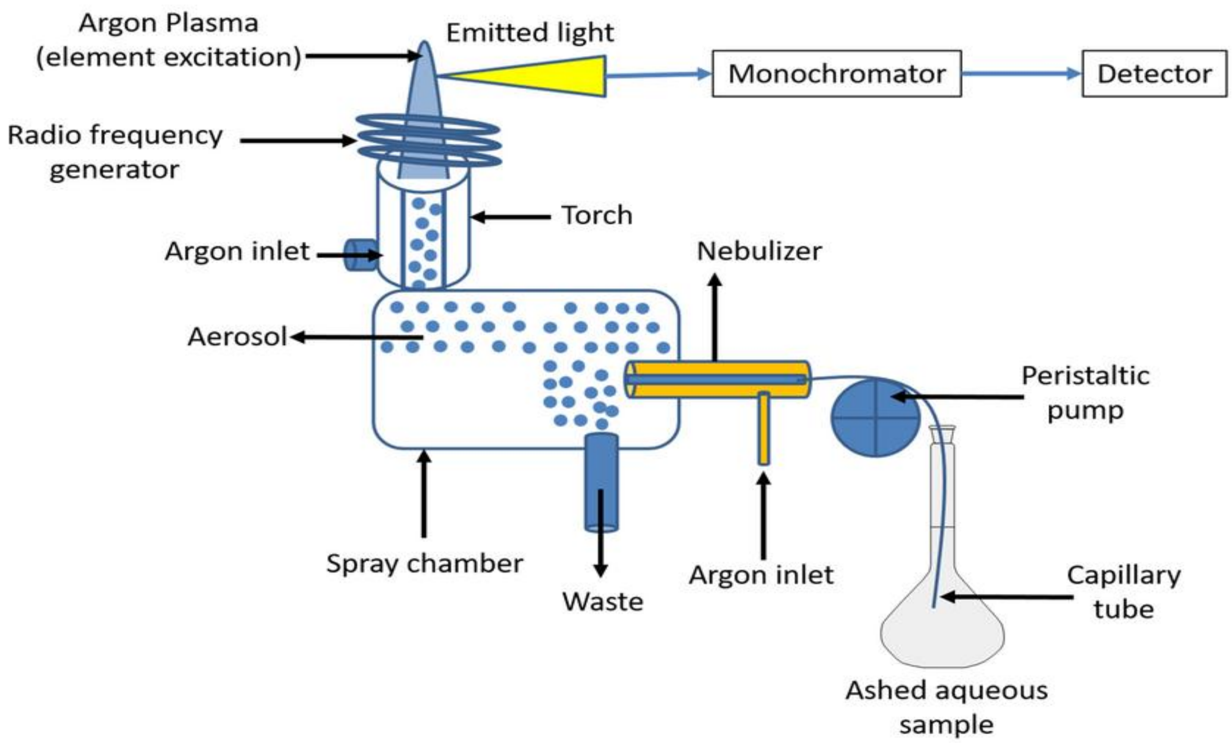
plasma (MCP). Inductively coupled plasma is the most frequently used Plasma for the more valuable study of samples. It conducts electricity and is affected by magnetic fields. They are a form of highly magnetic and ionized gases produced from noble gases.

6.3 Monochromator

As a monochromator Prism or grating is used. As the atom reaches its ground state, the emitted radiation passes through the monochromator that separates the specific Wavelength for desired analysis.

Fig 5: Schematic diagram of inductively coupled plasma emission spectroscopy (ICP-AES)



6.4 **Detector**

The light selected by the monochromator passes to the detector.Photomultiplier tube is used as a detector inAtomic emission Spectrometer. They are used to convert optical signals into electrical current which is then amplified by the amplifier.

6.5 Recorder

After converting the electrical signal, the detector sends those signals to the recorder to convert them into an understandable response. Nowadays, we use a computer system with suitable software for recording signals. A calibration curve is used to determine the unknown concentration of an element.

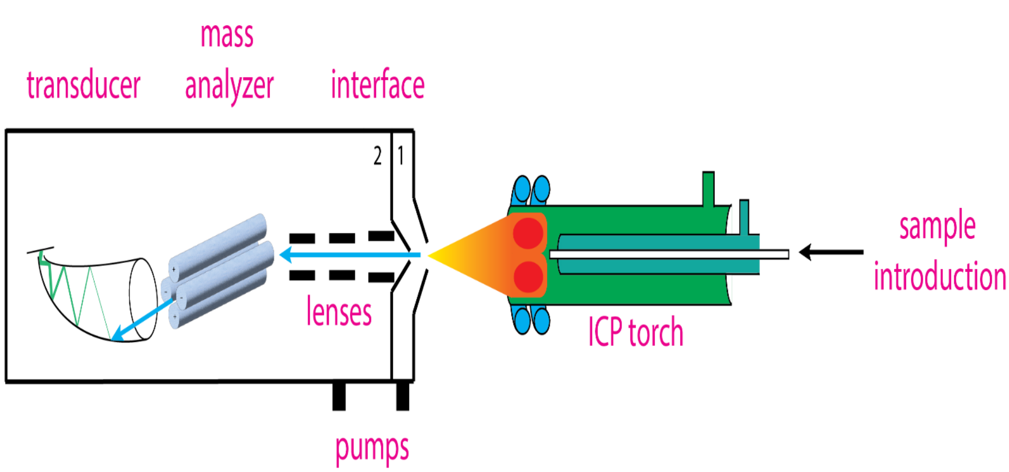
7. Inductively coupled plasma mass spectroscopy (ICP-MS)

It is a technique that is used to determine very low-concentration elements (ppb and ppt). Firstly, atomic elements pass through a plasma source when they become ionized then; these ions are sorted based on their mass. In comparison toAtomic absorption spectrometer (AAS) or inductively coupled plasma emission spectroscopy (ICP-AES), this technique is very useful because it has excellent detection power, large linear range, and precision. There are six common components of inductively coupled plasma emission spectroscopy (ICP-AES). These are; the sample introduction, inductively coupled plasma, interface, ion optics, mass analyzer, and detector.

7.1 Detection system

Firstly, a liquid sample is nebulised in the sample Introduction system, creating a fine mist, after that it is transferred to the argon plasma. The high-temperature plasma atomises and ionises the sample, generating ions which are then extracted region and into a set of electrostatic lenses is known as ion optics. The ion optics leads the ion beam into the mass analyzer. The mass analyzer separates ions according to their mass. Then these ions are measured in the detector.

Fig 6: Schematic diagram of inductively coupled plasma mass spectroscopy (ICP-MS)



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Unlike, atomic absorption spectroscopy, which can only measure a single element at a time, inductively coupled plasma emission spectroscopy (ICP-AES) can scan for all elements at the same time. This allows rapid sample processing. The fast scanning, large dynamic range and large mass range are ideally suited to measuring multiple unknown concentrations and isotopes. Maintaining the plasma requires a continuous supply of gas and increased power consumption of the apparatus. When these additional operating costs are not acceptable, plasma and most systems can be turned off. In standby mode, only the pump is employed to maintain proper vacuum in the mass-spectrometer.

Food contains nutrients like proteins, fats, carbohydrates, and minerals which are considered a complete food in our daily diet. As industrial and agricultural processes have expanded, the concentration of physical, chemical, and biological hazards in the environment has increased. A significant amount of heavy metals found in plants end up in food, which harms both the quality of products and human health. For decades, these techniques have been used for food analysis and many other applications. Many food items are analyzed for harmful heavy elements with the help of these instruments. In the last decade, the use of these devices in food and beverages has seen a significant increase.

8. Comparison between these detectors

High purity Germanium (HPGe) detector is widely used to detect Gamma rays and x- rays because of their high resolving power and photon detection efficiency. HPGe detector recorded higher activity concentrations of ^{238}U and ^{232}Th, hence more efficient in detecting isotopes with low energies than the NaI (Tl) detector. Whereas, NaI (Tl) detector measures a higher activity concentration of ^{40}K on average, and is more efficient in detecting isotopes of high energies than the HPGe detector. So, we can say that HPGe detector is more efficient in detecting gamma rays of low energy but less efficient in detecting gamma rays of high energy compared to the NaI (Tl) detector.Whereas GM counter is used for detecting or measuring ionizing radiation (alpha, beta, gamma, and X-rays). Uncharged particles like neutrons cannot be detected in GM counter. GM counter is widely used in experimental physics, radiological protection and radiation dosimetry.

The Flame AAS is ideal if you wish to measure concentrations above 100 ppb in a small number of samples. Using a flame atomic absorption spectrometer you can measure the alkali metals (Li, Na, K, Rb, Cs, Fr) and some heavy elements such as lead (Pb) and cadmium (Cd) or the transition metals manganese (Mn) and nickel (Ni). The Atomic absorption spectrometer takes 10-15 seconds per element for each sample.If you want to measure chlorine (Cl) and iodine (I) or

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radioactive elements technetium (Tc) and promethium (Pm) inductively coupled plasma atomic emission spectroscopy (ICP-AES) is the best choice compared to atomic absorption spectrometer (AAS). Inductively Coupled Plasma Atomic Emission Spectrometer takes 1 minute for each element.if you want to measure low-level elements such as Plutonium (Pu), Americium (Am) and radioactive elements Neptunium (Np), Bromine (Br) or any obscure actinides elements such as Actinium (Ac), Berkelium (Bk), californium (Cf), curium (Cm), Protactinium (Pa) and Polonium (Po) then inductively coupled plasma mass spectroscopy (ICP-MS) is the only choice to measure these elements.

9. Conclusion

It concluded from the entire review that these detectors are mainly used to determine radioisotopes even trace elements in food stuff. It just does not determine the concentration of elements but also determine which elements are present in the food. So we can say that these detectors are a useful tool to determine the radioisotopes and heavy elements.

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