Chapter 38

Inertial Electrostatic Confinement Source for Contraband and Illicit Material detection

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Neutron Activation Analysis (NAA) technique is based on nuclear reactions using neutrons interacting with samples in the energy range from thermal to several MeVs. The exposed sample becomes radioactive when irradiated with neutrons. Short lived radionuclides are formed during exposure with neutrons, which subsequently decay by emitting characteristic gamma rays of specific half-life and energy. Unlike any other analytical techniques for detection of illicit and contraband materials, neutron activation analysis is a non-destructive and prompt method. The exposed samples with neutrons can be handled with in short time after their irradiation. NAA technique requires a neutron source. These neutrons could be provided from nuclear reactors, radioisotope (Pu-Be, Am-Be etc) or sealed fusion neutron source (DD, DT). Sealed fusion source are ideal for NAA as they are compact, portable and minimises the radiation hazards. Inertial Electrostatic Confinement (IEC) fusion neuron source is designed and fabricated indigenously for NAA of illicit and contraband materials.

38.1. Inertial Electrostatic Confinement Neutron Source

Inertial Electrostatic Confinement (IEC) fusion is an alternating fusion concept compared to inertial confinement fusion and magnetic confinement fusion. The fuel gas ions of DD,DT are confined in convergent geometry using electrostatic fields. It is simple to construct IEC device as compared to other neutron sources. IEC source operates in glow discharge region of paschen curve (Figure 38.1). High voltages up to 10 –100 kV is applied across the anode-cathode gap in concentric geometry to produce ions and accelerate it.

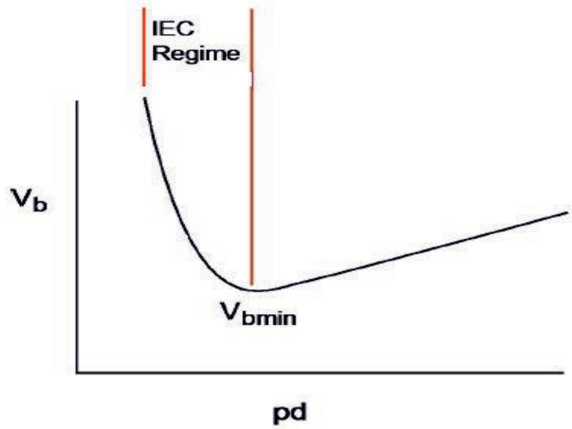

Figure 38.1. Regime of IEC operation.

The positive deuterium ions are produced by applying high voltages across the concentric grids. These deuterium ions are accelerated towards the cathode by electrostatic fields and undergo nuclear fusion reactions in the centre of cathode. Due to application of higher voltage across the concentric grids, the ions are pulsed across the potential well in the central region. Nuclear fusion occurs in the central region in a zone of low potential because to collision of deuterium fuel ions moving in opposite directions (Figure 38.2.)

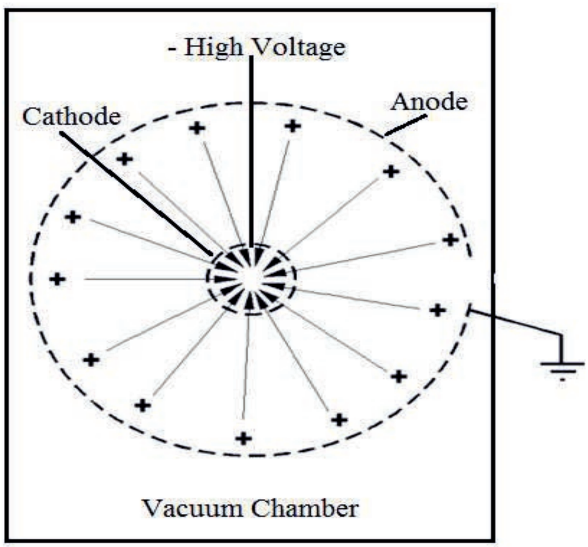

Figure 38.2. Anode and Cathode Grids in IEC System.

A typical IEC plasma device consists of two concentric electrodes with convergent geometries placed in the vacuum chamber. The potential across anode-cathode (φ) and cathode radius r_g determines the oscillation frequency (ʋ) of the deuterium ion in plasma [1].

$$\upsilon = 8\text{x}10^6 \frac{\sqrt{\varphi}}{r_g} \qquad (38.1)$$

Where, φ is in (kV)

r_g is in (cm)

ʋ is in (Hz)

The deuterium ion plasma density is

$$n_i = 2.7\text{x}10^2 \text{ x} f \text{x} \varphi^{3/2} \upsilon^2 cm^{-3} \qquad (38.2)$$

The calculation of rate of generation of neutrons is

$$\frac{dN}{dt} = \frac{1}{2} {n_i}^2 \sigma(\epsilon_i) U \,\Omega \text{ particles/second} \qquad (38.3)$$

where $\sigma(\epsilon_i)$ is the reaction cross section of the deuterium ion at a specific energy,

ϵ_i is calculated from the plot of reaction cross section and deuterium ion energy,

Ω is the volume of maximum deuterium ion density.

IEC Neutron source is designed and developed using concentric spherical SS grids and placed inside the vacuum chamber (Figure 38.3). The inner and outer grid is made up of SS rods. When negative polarity high voltage (10 – 100s kV) is applied to the inner SS grid and other SS grid is connected to ground, the deuterium plasma is confined inside the inner spherical grid (Figure 38.4). This spherical IEC system has produced > 10^5 n/s at 25 kV applied potential with deuterium gas at 0.02 mbar [2].

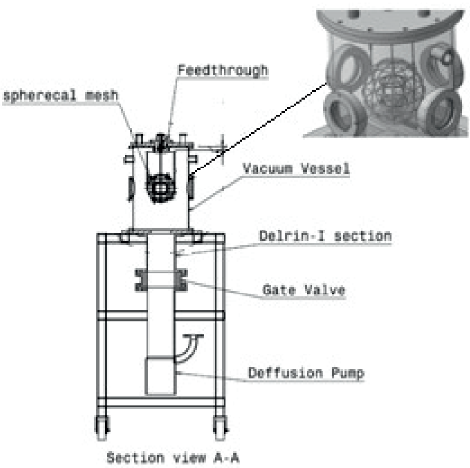

Figure 38.3. Spherical IEC system.

Figure 38.4. Plasma inside Grids.

High input power operation is required to enhance neutrons production rate in IEC source. However, when IEC operates at high input power, the cathode is usually heated excessively. To avoid overheating of the cathode, cylindrical cathode with 100% transparency is designed (Figure 38.5), it does not intercept ion beam and extremely reduces heat load to the cathode [3].

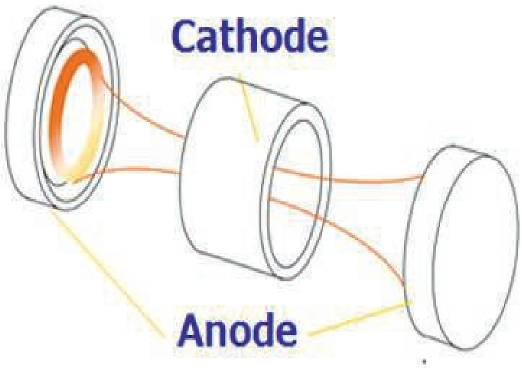

Figure 38.5. Cylindrical IEC System.

38.2. Detection of Contraband and Illicit Materials

Detection of trace amounts of explosives, contraband, illicit and radioactive materials hidden in cargo is a high priority and needed for nations security. There are different detection techniques including mass spectroscopy, X-ray screening etc. Neutron interrogation using radiography and activation can also be used for detection of traces of these materials. Neutrons are difficult to shield and can pass through any material with very small attenuation, so this techniques has several advantages over other methods. Gamma rays and X-rays can be shielded and blocked by high atomic number (Z) materials [4-6]. Neutron induced prompt activation reactions producing prompt and delayed gamma can be used to identify the elemental compositions of the any material. Neutron based nuclear techniques can be widely used for the detection of explosives, illicit, radioactive and contraband materials. The schematic diagram of neutron based detection technique is shown in Fig 38.6. The sample is irradiated with pulsed neutrons from IEC neutron source. The prompt and delayed gamma rays are measured with BGO detector. The data is acquired using fast digitizer and spectrum analysis is done in personal computer. Neutrons inducted activation reactions are also effective in differentiating between various materials. Neutron based detection techniques generates better results for security. Other neutron based techniques are fast neutron activation (FNA), thermal neutron activation (TNA), pulsed fast neutron activation (PFNA), pulsed fast thermal neutron activation (PFTNA) and neutron radiography. IEC neutron source developed will be used for detection of contraband, radioactive and illicit materials using these techniques.

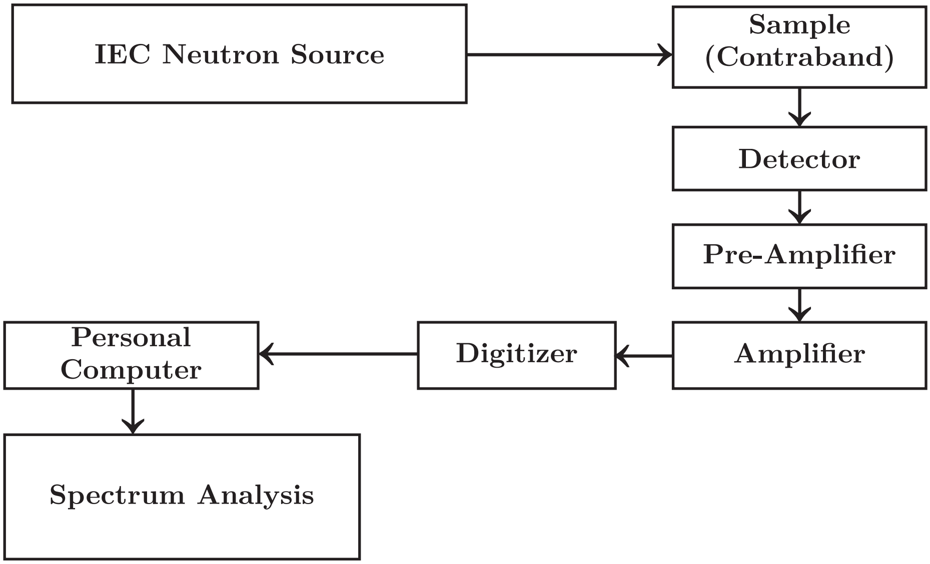

Figure 38.6. Schematic of detection system.

References

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