ABSTRACT

In order to understand and appreciate the effect of the capacitive decay in the detector-circuit during the charge collection on the response of ionization detectors, we have carried out Monte Carlo simulation of the response of fully depleted silicon surface barrier detectors, two-electrode parallel plate ionization chambers and gridded parallel plate ionization chambers for energetic heavy ions. These simulations have been carried out incorporating the physical processes, namely, charged particle emission from a point source, ionization in the active volume, separation and transport of charge carriers, induction of charges on the electrodes, pulse shaping with a CR-RC network having pole-zero cancellation, etc. These simulations have shown that the concerned capacitive decay produces appreciable loss in the pulse-height, if the detector-circuit time constant is of the order of maximum collection time of charge carriers. We have also carried out measurements on the pulse-height loss due to the capacitive decay in the detector-circuit during the electron collection for a two-electrode parallel plate ionization chamber. The experimental data on the pulse-height loss match reasonably well with the theoretical predictions.

In order to explore the possibility of using the pulse-type two-electrode parallel plate ionization chamber as a tool for identifying the alpha activities due to different natural alpha emitters found in the rock samples, sediments and environment, we have carried out Monte Carlo simulations of the energy response of the two-electrode parallel plate ionization chamber after placing a collimator of the angular opening defined as $0^\circ \leq \theta \leq \theta_{max}$ (with θ_{max} = 2°, 4° or 6°) or $\theta_{min} \leq \theta \leq 90^\circ$ (with θ_{min} = 84°, 86° or 88°) on the cathode plate having source on it. It is well known that the pulse-height spectrum for the two-electrode parallel plate

ionization chamber is rectangular in shape with the lower bound due to alpha particles making angle 0° with the electric field, the upper bound due to alpha particles making angle 90° with the electric field and any other point on the spectrum due to alpha particles making angle θ, $0^\circ < \theta < 90^\circ$. Clearly, by restricting alpha particles of narrow range of angles, the response of the chamber can be reduced to a narrow peaking pulse-height spectrum. The above simulations have shown that the detector can be used as an effective tool in studying the natural alpha radioactivity on the basis of energy dispersive analysis after placing a collimator of angular opening of $0^\circ \leq \theta \leq 2^\circ$ or $88^\circ \leq \theta \leq 90^\circ$ on the cathode plate having source on it. The optimized electrode separation for $0^\circ \leq \theta \leq 2^\circ$ is about 25 cm and that for $88^\circ \leq \theta \leq 90^\circ$ is about 12 cm. We have also carried out measurements on the energy response of the two-electrode parallel plate ionization chamber with an angular opening of $86^\circ \leq \theta \leq 90^\circ$. The experimentally observed energy response matches well with the theoretical prediction.

In order to understand the dependence of the ballistic deficit on the shape of rising portion of the voltage pulse at the input of pulse shaping amplifier, we have estimated the ballistic deficits using numerical integration method for the pulses from the two-electrode parallel plate ionization chamber as well as for the pulses from the gridded parallel plate ionization chamber when processed through the CR-RC^n (n = 1 - 6) shaping network, ORTEC 440A amplifier and ORTEC 472 spectroscopic amplifier. These estimations have clearly shown that the ballistic deficit depends upon the shape of rising portion of the voltage pulse at the input of pulse shaping amplifier, the type of the pulse shaping network and the shaping time. The ballistic deficits for the pulses from the two-electrode parallel plate ionization chamber are found to be severe when rising portion of the voltage pulse at the input of pulse shaping amplifier is a linear ramp whereas that for the pulses from the gridded parallel plate ionization chamber are found to be severe when rising portion of the voltage pulse has shape other than a linear ramp. Under all conditions, the highest ballistic deficit is for the ORTEC 472 spectroscopy amplifier and the lowest is for the $CR\text{-}RC^6$ shaping network. We have also carried out measurements of the ballistic deficits for the pulses from the two-electrode parallel plate ionization chamber as well as for the pulses from the gridded parallel plate ionization chamber using a linear amplifier having a simple CR-RC shaping network. The experimental data on the ballistic deficits match reasonably well with the theoretical predictions and clearly show that the ballistic deficit for these pulses can be made quite small by choosing the shaping time about four-times the maximum electron collection time. The Monte Carlo simulations of the pulse-height spectra for the two-electrode parallel plate ionization chambers as well as for the gridded parallel plate ionization chambers have clearly shown that there is an asymmetrical broadening due to ballistic deficits in the lower side of the pulse-height spectra when the shaping time is less than four-times the maximum electron collection time.

The measurements on the differential scattering cross section of alpha particles from ${}^{27}_{13}Al$ at 30° for alpha particle energies in the range 4.0 - 8.0 MeV with 0.5 MeV energy interval have shown that the scattering is dominated by non-Rutherford processes for alpha particle energies above 4.0 MeV, indicating large contribution of nuclear potential scattering. Two broad nuclear resonances have been observed at alpha particle energies 5.0 and 7.0 MeV, each containing several resonances observed in the past. The estimated Q-values (energies available) for the reaction ${}^{27}_{13}Al(\alpha,p){}^{30}_{14}Si$ corresponding to different alpha particle energies in the range 4.5 - 8.0 MeV confirm the emission of protons due to the compound nucleus process. In addition to the seven levels with energies 5.50, 5.62, 5.94, 6.52, 7.10, 7.38 and

8.40 MeV in the $^{30}_{14}Si$ nucleus, already reported in the literature, we have observed a new energy level with 6.33 MeV energy in the present work.

Keywords: Ionization detector; Capacitive decay; Simulation; Pulse-height spectrum Natural alpha radioactivity; Shaping time; Ballistic deficit; Energy levels.