Studies on (i) Characterization of Bremsstrahlung spectra from high Z elements and (ii) Development of Neutron source using MeV pulsed electron beam and their applications

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Introduction

Particle accelerators which have initially been developed as a tool for basic research now have well known applications in industry, applied sciences and medical. There are more than ten thousand of accelerators running all over the world. Out of which almost fifty percent are devoted to the medical applications. The main areas of use are radioisotopes production, radiography and conventional radiotherapy with electron and photon beams. Electrons and photons are found to be good members of radiation therapy for treating the cancer, quite years ago. This is because of their high penetrability, low Linear Energy Transfer (LET) to exhibit damage to the normal cell and unique characteristics of dose distribution at depth. With the advent of high energy linear and circular accelerators, electron / photon have become a viable option in treating superficial tumors up to the depth of about 5-10 cm.

In earlier works, the neutrons produced in reactors or through D-T reaction were mainly used to study the nuclear reactions, measurement of cross sections and elemental analysis in different materials because of their high neutron flux. But, recently the attention has been paid to use these neutrons in various fields such as medical, engineering, defense, geological and industries. The main stream of these applications are irradiation of biological samples, neutron induced damage in an electronic devices, activation analysis, fissile element content determination, detection of explosive class materials, etc. Moreover, the wide range of applications of neutrons have been covered due to their properties such as being a neutral particle with high penetrating power, magnetic moment and comparable wavelength with atomic spacing. This helps to investigate not only the nuclear system but also analysis of materials such as reconstructing the magnetic microstructure, determination of crystal structures, etc. However, in recent years, there have been a rapid growth in case of electron accelerator based neutron sources for medical and industrial applications because of their compactness, easy handling, adjustable flux, no radioactive waste, less shielding requirement, etc.

Therefore, in the present thesis considering the importance of electron, photon, fast neutrons and thermal neutrons in the medical and industrial field, the actual evaluation and designing aspect of the associated accessories of the sources have been studied thoroughly.

Materials and Methods

To perform the accelerator based research, a 6 MeV electron accelerator called Race -Track Microtron at Pune Univeristy, and 6 MeV, 15 MeV electron accelerator called LINAC (LINear ACcelerator) at Society for Applied Microwave Electrical Engineering and Research (SAMEER), Mumbai has been used in the present study. In addition, the results are also estimated for the energies 9 MeV, 12 MeV and 18 MeV.

The radiation field of electron accelerator includes several components such as electrons, bremsstrahlung, fast neutrons, positrons, etc. The production and transport of all these radiations through different targets are difficult to study theoretically even on the basis of correct experiments. Therefore, a computer code allowing a suitable simulation of the entire process of photoneutron generation and transport across the different targets represents a useful tool. Therefore, a general purpose Monte Carlo based code FLUKA [1] has been used for the calculations of particle transport and interactions with matter. Moreover, the possibility of managing complex geometries and performing simulation in a reasonable time is a fundamental requirement of the code.

Outline of the Thesis

As to electron accelerators, we have now really well developed LINACs and Microtrons (circular and Race-track) for various applications worldwide. Interaction of high energy electrons with high Z target produces a flux of gamma quanta, called bremsstrahlung radiation. Radiotherapy using electron and bremsstrahlung radiation represents the most diffused technique to control and treat tumor diseases. Looking at this important aspect, the problem of the present thesis has been defined and divided into six subparts. The first part of the thesis mainly deals with the design of dual scattering foil for 6 to 20 MeV electron beam of LINAC in clinical applications. The dual scattering foil has been optimized using FLUKA code such that the primary scattering foil was kept uniform thickness, whereas the secondary foil was of Gaussian shape with varying thickness and the results compared with analytical calculations.

The study of bremsstrahlung spectra from 6 to 18 MeV electron beam from different material (low to high Z elements) as $e - \gamma$ target has been studied in the second part of the thesis. The simulation using FLUKA involves the fluence determination of neutron, electron and positron along with photon at various angles. The data generated in this part can be used as right hand data for the researchers and medical physicists. In addition the reliability of FLUKA simulation was confirmed by calculating the spectra for the experiments performed by other researchers.

The third part of the thesis includes the estimation of neutron contamination in clinical photon beam generated from optimized accelerator head assembly through photonuclear reaction. The $e - \gamma$ target, primary collimator, secondary collimator and filter of accelerator head assembly of 15 MV medical LINAC has been designed through FLUKA simulations. The electron accelerators operating above 10 MeV can result in the production of neutrons, mainly due to photo nuclear reaction (γ,n) induced by high energy photons in the accelerator head materials. These neutrons contaminate the therapeutic beam and give a non negligible contribution to patient dose. The gamma dose and neutron dose equivalent at the patient plane were obtained at different field sizes and maximum neutron dose equivalent observed near the central axis of of 30×30 cm^2 field size.

The electron accelerator based neutron sources are found to be an advantageous over radioactive based neutron sources and has various applications in industries. Therefore, in fourth part of the thesis, emphasis given on the measurement of angular distribution of neutron flux for the 6 MeV Race-Track Microtron based pulsed neutron source for short lived activation product analysis. In this case, the neutron flux was measured using activation analysis technique and the same has been modeled in FLUKA for comparison. The results indicate that the neutron flux was found to be decreased as increase in the angle and in good agreement with the FLUKA simulation. Moreover, (n,α) reaction with boron has been studied using 6 MeV Race-Track Microtron based pulsed neutron source.

In the fifth part of the thesis, 6 MeV linear accelerator based pulsed thermal neutron source has been designed for elemental analysis. In this design, all the possibilities to get highest neutron flux was checked and the $\gamma - n$ target, moderator, reflector, shielding material have been optimized. A prototype experiment was carried out and corresponding experimental results were compared with simulated one. The results of experiment and simulation are found to be in good agreement with each other.

In the sixth part of the thesis, the 15 MeV linear accelerator based neutron radiography facility has been designed and development is in progress at SAMEER, Mumbai. In this case, a neutron collimator has been designed along with $\gamma - n$ target, moderator, reflector and shielding. To get best values of collimator parameters such as collimation ratio, gamma content, neuron flux, cadmium ratio, beam uniformity, etc. a FLUKA simulation was carried out. Radiography using the developed facility has been kept as future scope. However, some radiographs have been taken up using the neutron radiography facility of APSARA reactor at BARC, Mumbai for the study purpose.

Reference

[1] Fasso, A. et al. CERN-2005-10, INFN/TC-05/11, SLAC-R-773 (2005).