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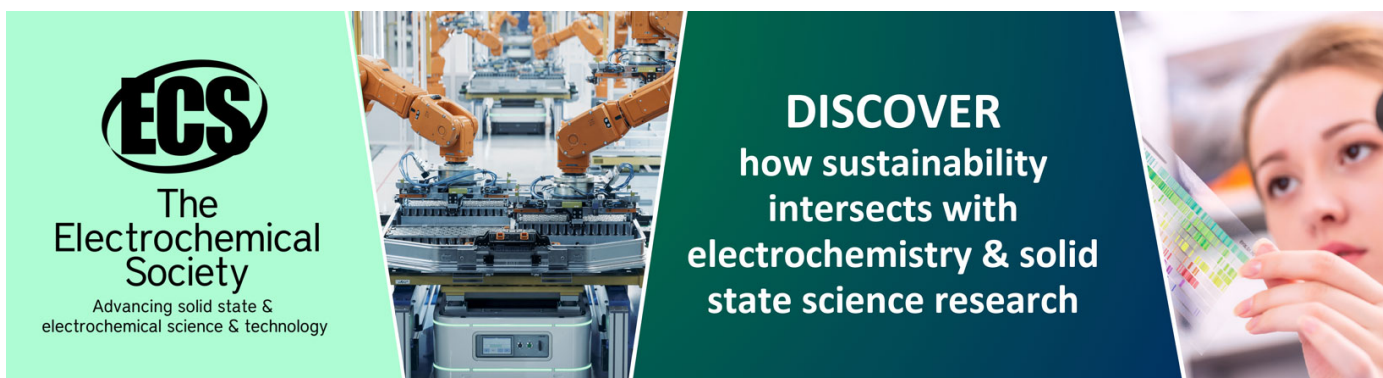
Measuring the stopping power of α particles in compact bone for BNCT

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Measuring the stopping power of α particles in compact bone for BNCT

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Abstract. The stopping power of α particles in thin films of decalcified sheep femur, in the range of 1.5 to 5.0 MeV incident energy, was measured by transmission of a backscattered beam from a heavy target. Additionally, the film elemental composition was determined by Rutherford Backscattering Spectrometry (RBS). These data will be used to measure boron concentration in thin films of bone using a spectrometry technique developed by the University of Pavia, since the concentration ratio between healthy tissue and tumor is of fundamental importance in Boron Neutron Capture Therapy (BNCT). The present experimental data are compared with numerical simulation results and with tabulated stopping power data of non-decalcified human bone.

1. Introduction

Boron Neutron Capture Therapy (BNCT) is a cancer treatment that was designed to selectively deliver heavy charged particle radiation to tumors at the cellular level. This technique takes advantage of the high Linear Energy Transfer (LET) products of the $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction and the selective boron uptake by tumor cells. After capturing a thermal neutron, ^{10}B becomes ^{11}B , which immediately disintegrates into ionizing particles that have a range in tissue comparable with cellular dimensions ($\sim 12\text{-}14\ \mu\text{m}$). Then, if an adequate amount of boron is selectively concentrated in a tumor and the volume is exposed to thermal neutrons, a higher radiation dose is absorbed by the tumor in comparison to adjacent normal tissue.

The establishment of an appropriate boron concentration ratio between healthy tissue and tumor after administration of a boron compound is one of the fundamental aspects that ensure the clinical effectiveness of BNCT. In order to assess a proper dosimetry, it is thus necessary to know the boron concentration of the tissues irradiated by neutrons. The charged particle spectrometry developed in the University of Pavia [1] allows determining boron concentrations down to 1 ppm in thin soft tissue sections. Extending this technique to analyze hard tissues of interest in osteosarcoma disease requires the knowledge of the stopping power of α particles in these tissues. However, as thin samples are required, the calcium concentration of bone were reduced so that it can be cut with conventional cryostat. Transmission experiments using α particles in thin films of compact bone were performed in an energy range from 1.5 to 5.0 MeV, range wich includes those energies resulting from the neutron capture reaction.

2. Materials and Methods.

2.1. Sheep femur samples.

Compact femur from a sheep was decalcified using Ethylenediaminetetraacetic acid disodium salt (EDTANa) 0.5 M. The decalcifying method consisted in the immersion of small samples of sheep



femur in the EDTANa solution, renewed weekly, during three weeks. After decalcification the samples were sectioned in different nominal thicknesses between 10 μm and 30 μm . The area and weight of each sample were also measured. Pictures of the samples were taken using a stereomicroscope and the program ImageProTM [2] was employed to measure their area. The weight was measured using a digital scale with a resolution of 0.001 mg.

The elemental composition of the decalcified sheep femur was measured by using Rutherford Backscattering Spectrometry (RBS) in 30 μm thickness sample. In brief, RBS consists in a monoenergetic ion beam (here α particles) backscattered by nuclei of the elements presents in the sample, with an outgoing energy that depends on the nuclei mass. The energy distribution of the scattered α particles extends from a maximum, for nuclei at the sample surface, to lower energies due to the beam energy loss in the incoming and outgoing trajectories for nuclei at the bulk [3]. The measured spectra were analyzed with the SIMNRA software [4] that fits the experimental data by varying elemental concentrations, using a database of scattering cross sections. For the present work, as an initial guess was used the composition reported by ICRU 46 [5] and adding the elements of the decalcifying solution.

2.2. Experimental set-up.

The experimental set-up for the stopping power measurements is shown in figure 1. High doses delivered by the direct α particles beam could damage the sample as well as the detector, and in order to avoid this effect a secondary scattered beam was used instead. The primary beam coming from the accelerator impinges normally on the main target consisting in an oxide film grown on silicon substrate. The thickness of the oxide layer (~ 50 nm) assures a secondary scattered α particles beam of well-defined energy to the purpose of a transmission stopping experiment. By using two heavy elements oxide, uranium (UOx) and zirconium (ZrOx), secondary beams with different energies near to the maximum of the accelerator capability can be obtained.

A detector positioned 40° apart from the beam line measures the energy distribution of the secondary α particles beam. Calibration spectra were recorded for each ion beam energy and both oxide targets. Afterwards, spectra were measured with different sections of decalcified compact bone interposed in the path of the secondary beam. These films placed in front of the detector move the spectra to lower energies. The shifting of the spectra allows deriving the stopping power [6]. In order to work within the range of interest, the energy of main ion beam was set between 1.5 and 5.0 MeV, in a NEC 5SDH, 1.7 MV Tandem Accelerator at Centro Atómico Bariloche.

The measurements of elemental composition using RBS was performed with a 2.0 MeV α particles beam, and the detector placed 15° apart from the beam line. The energy loss simulations were carried out with SRIM [7] software, using the previously measured composition.

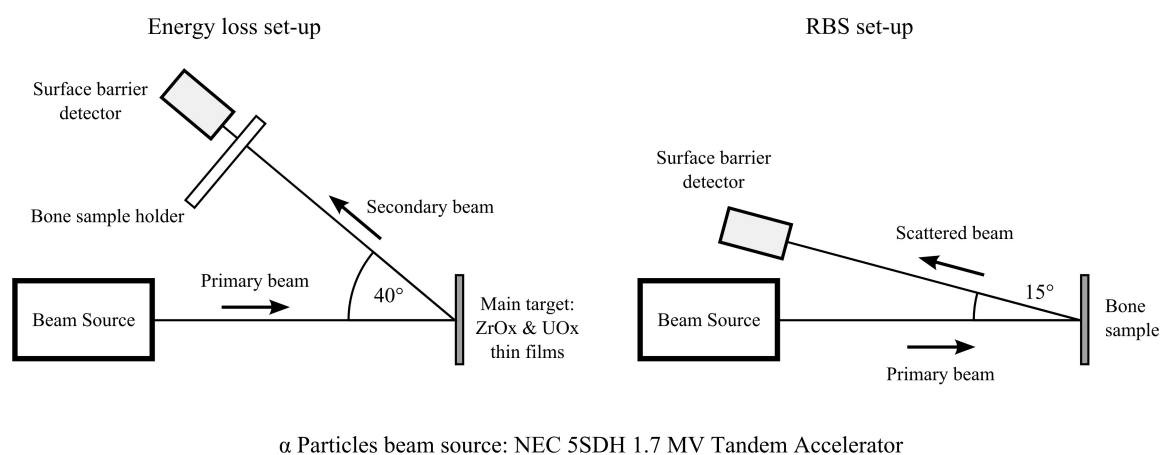


Figure 1. Experimental set-up.

3. Results and Discussion.

Figure 2 shows the experimental RBS spectrum for a decalcified thick bone sample alongside the SIMNRA fitting. The contribution of each chemical element is also depicted. On the right side the resulting elemental composition of the sample in atomic percentage is listed.

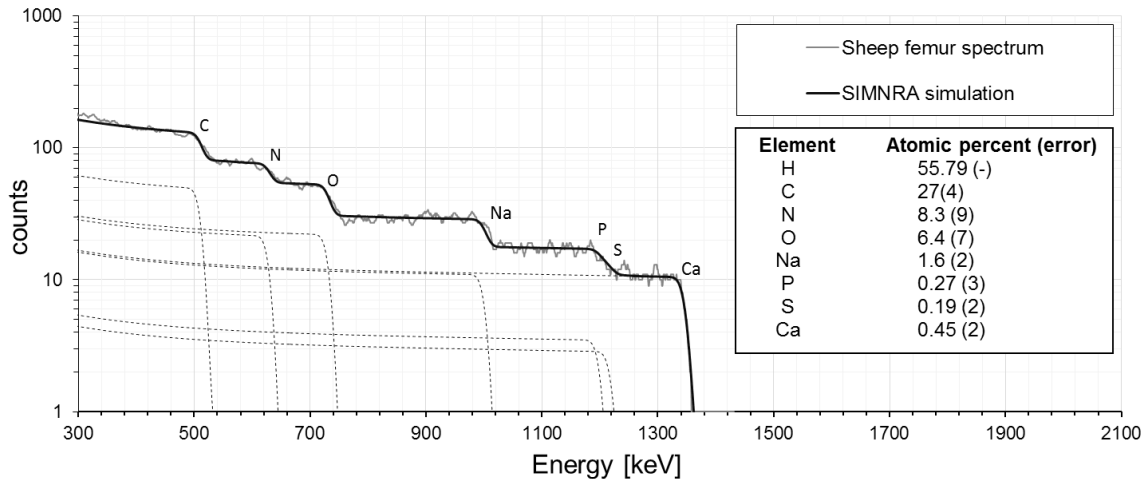


Figure 2. Measured α particles RBS spectrum of a decalcified sheep femur sample with SIMNRA fittings and chemical composition results (inset table).

Figure 3 shows the calibration spectra for uranium and zirconium oxides films (UOx and ZrOx, respectively) measured with 4 MeV beam energy. Note that the low thickness of the film mimic the behaviour of an α particles source with a narrow energy distribution. In figure 4, the UOx calibration spectrum and the one obtained after the secondary beam passed through a 0.905 ± 0.004 mg/cm² femur sample are presented. The shift in the energy of the main peak belonging to the U scattering as well as the modification in the plateau corresponding to the substrate (Si) are clearly seen in the plot.

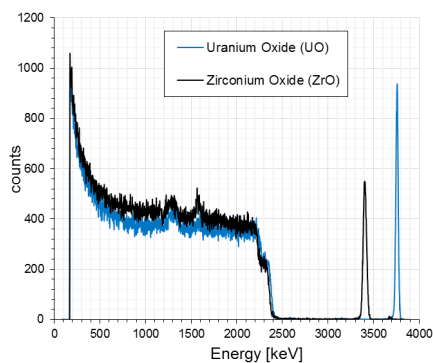


Figure 3. Calibration spectra of UOx and ZrOx targets with 4 MeV α particles main beam.

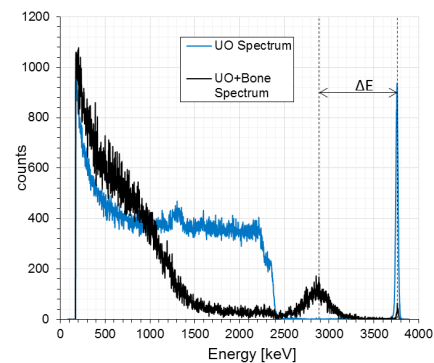


Figure 4. Comparison between the spectra of UOx target and the corresponding one with a 0.905 ± 0.004 mg/cm² femur sample interposed.

The results of the measured α particles energy loss as a function of the initial particle energy for two different sample thicknesses are shown in figure 5. From this experimental data, the functional relation between the final energy of α particles and the surface density (mg/cm²) of the samples was determined. A 9th degree polynomial was used to interpolate the discrete results and also to obtain an easily differentiable smooth curve.

In Figure 6 the α particles stopping power calculated from the differentiation of the polynomial fit (with 95% prediction bounds) is compared with the values reported in ICRU 49[8] for human compact bone, only for reference. SRIM simulation results based on the sheep femur composition measured in this work is also plotted. As can be seen, the simulation overestimates the experimental stopping power. Given that the decalcification process acts from the surface to the center of the bone sample, different thin slices might have different elemental composition. Then, the overestimation could be due to the fact that the energy loss and the elemental composition measurements were performed in different sheep femur slices.

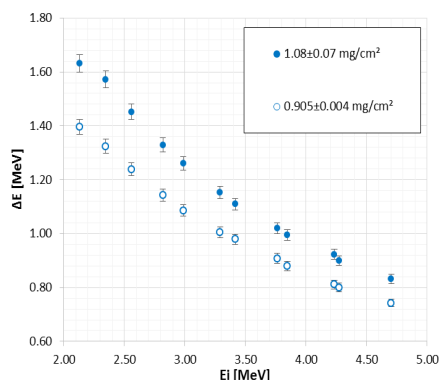


Figure 5. Energy loss of α particles in decalcified compact bone (sheep femur) as a function of the initial particle energy for two sample thicknesses.

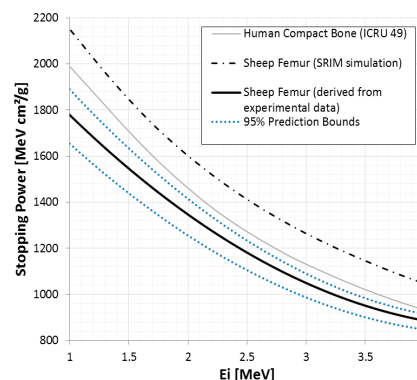


Figure 6. Stopping power of α particles derived from experimental data, compared with SRIM simulation results and data for human compact bone reported in ICRU 49.

4. Conclusions and future work.

Energy loss of α particles as a function of incident energy was measured in sheep femur samples with different thicknesses, from these experimental results the α particle stopping power was derived. Simulations of the stopping power made with SRIM software were also carried out using the chemical composition of compact bone measured with RBS on a thick sample of the same femur.

Further experiments to study the impact in the stopping power of different chemical composition for consecutive slices from the same decalcified bone are in progress.

References

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