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Energy device for monitoring 4-10 MeV industrial electron accelerators

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Abstract

The electron beam energy is one of the critical parameters of electron accelerators since it can affect the dose distribution inside the body or in products to be irradiated with a beam of energetic electrons. A device has been developed for monitoring small variations in the electron beam energy that is easy-to-use during an irradiation run. It involves measurement of currents (or charges) collected by two identical aluminium plates, except for their thickness, and electrically insulated from each other, located in the beam. The ratio of these two currents (or collected charges) is quite sensitive to the beam energy; optimization of sensitivity is obtained by selecting the appropriate thickness of the front plate depending on the beam energy. In the present paper, we have investigated the feasibility of using this energy device at energies, from 4 to 10 MeV.

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1. Introduction

For radiation processing using electrons from an accelerator, the beam energy is one of the critical process parameters. Any small variation in the beam energy could affect the depth-dose distribution in the product and thus the irradiation process itself; this effect can be more significant for two-sided irradiation.

It is a general practice at an irradiation facility to determine the electron beam energy by measuring depth-dose distribution in a reference material; quite often this material is aluminium. In our previous paper [1] we have described a robust energy device that can be used very conveniently for monitoring small changes in beam energy during an irradiation run. The principle of that device is based on the fact that beam energy variation affects the charge-deposition distribution, just like dose distribution. The main difference is that the charge or current can be measured almost on-line, unlike dose.

Our earlier work was carried out in the energy range of 7-12 MeV at ISOF accelerator [1]. In the present work we are reporting on the feasibility of using such a device at lower energies, namely from 4 to 6 MeV.

2. Experimental

2.1. Irradiation source and geometry

All tests were carried out at the Institute of Isotopes (I.I.) using the 4 MeV nominal energy TESLA LPR-4 type linear electron accelerator (I.I. accelerator). This accelerator produces an electron beam with an average energy of 3–6 MeV, with either single electron pulses or a continuous train of pulses at a frequency of 50, 25, 12.5 or 6.25 Hz [2]. The pulse length is 2.6 μs or 800 ns. The electron beam can be scanned by an electromagnetic system at a frequency of 1 Hz.

For present investigation, the irradiation of the energy device was carried out with the vertical beam using 2.6 μs electron pulses at a frequency of 50 Hz. The energy of the beam was varied by changing the electron current from its maximum value (100 % = 20 μA) to 10 %. The energy device was located 20 cm under the Ti accelerator window. The depth-dose distribution (to determine the beam energy) was measured at the same irradiation location before and after the energy device irradiation.

2.2. Energy device

The energy device used for the present work was similar to that we have used and reported earlier [1]. The difference between the two energy devices is the thickness of the front collector plate, which is selected based on the energy of the electron beam. The optimum thickness of this plate is determined by the position of the peak in the differential charge-deposition distribution with depth in the material of construction (aluminium). We followed the same procedure for measuring the charge-deposition distribution that was reported earlier [1].

Based on the results of these measurements, the optimum thickness for the front plate was established as 5 mm of aluminium. The thickness of the back plate was kept 25 mm as before. These charge-collecting plates are placed inside an electrically grounded aluminium cage separated from each other by an air gap of 5 mm, and electrically insulated from the cage by ceramic pillars (see Fig. 1). We noticed that it was critical that the outer cage is carefully grounded to eliminate any influence of the ionized air surrounding the cage on the measurements.

To measure the currents collected by the two plates, they were connected by two long coaxial cables to a measuring instrument having two identical circuits, each was realized using an integrated circuit (IC) connected in the current amplifier configuration. This set-up does not use shunt resistance, thus avoiding the build-up of voltage drop between the collecting plate and the grounded cage. Also to minimise this voltage drop, the IC was selected so that the offset voltage and the temperature drift are as low as possible. The collection of pulses with relatively high charges with rise-time faster than the IC's reaction time and the long cables cause the build-up of parasite capacities, which can increase again the voltage drop between the plate and the ground. To avoid these occurrences, the circuit has a high value capacitor before the IC, which has low leakage, low hysteresis and low inductance. The measuring instrument was placed outside the irradiation room.

Aluminium was chosen as material for the energy device because of its ruggedness, ease of manufacture, low backscattering coefficient [3] and high threshold energy for (γ , n) reaction (E_{th}=13.1 MeV) [4].

When the energy device was under the beam, currents were measured from the two plates simultaneously. Energy ratio was then calculated as follows:

Energy ratio = Current from the front plate / Sum of the currents from the two plates

2.3. Beam energy determination with the aluminium wedge

The depth-dose distribution was measured by irradiating B3 film strips [5] (8 mm wide and 80 mm long) placed within a 60° aluminium wedge-pair [6]. The irradiated strips were read at 554 nm using a Spectronic Genesys 5 spectrophotometer manufactured by Milton Roy and equipped with an automatic strip-feed mechanism from AERIAL operating at a measurement resolution of 10 points/cm. The beam size of the analyzing light was 3 mm diameter, which determined the spatial resolution of the measured depth-dose distribution.

The practical electron beam range (R_p) and the half-value depth (R_{50}) in aluminium were then determined from these depth-dose distributions [7]. The value of R_p was then used to calculate the most probable electron beam energy (E_p) based on the following expression [3]:

$$E_p \text{ (MeV)} = 0.2 + 5.09\, R_p$$

3. Results

Figure 2 shows a typical depth-dose distribution for the I.I. accelerator using the aluminium wedge. From these data the practical electron beam range (R_p) and half-value depth (R_{50}) were determined as shown in the figure.

Table 1 lists all the data generated during one week for the present investigation. The energy of the beam was varied by changing the beam current (1st column), the range data (R_p and R_{50}) were generated using the aluminium wedge as shown in Fig. 2, most probable beam energy (E_p) values were determined using the expression given in section 2.3., and the energy ratio values with their coefficient of variation were calculated from replicate measurements of current values for the energy device (last column). The largest contribution to the uncertainty in E_p arises from the fact that the exposed B3 film is only about 15 mm long (because of the low beam energy) compared to the size of the analysing beam (Ø3 mm).

Data on energy ratio and electron beam energy from Table 1 are plotted in Fig. 3. Figure 4 shows the data of Fig. 3 (for the I.I. accelerator, beam energy of 4-6 MeV) along with similar data for ISOF accelerator with beam energy of 7-10 MeV from our earlier paper [1].

4. Discussion

The usefulness of the device as a monitoring tool for the beam energy depends on the assumption that the electron spectrum does not change significantly when the energy varies. The ratio R_p/R_{50} shown in Table 1 is an indication of the constancy of the electron spectrum when the energy is varied [7].

To be able to use the energy device as a monitoring tool for the electron beam energy, it is necessary to establish a relation between the output of the energy device (energy ratio) and the electron beam energy. The data in Fig. 3 show that there is a good linear correlation between these two parameters, suggesting that this relationship can be exploited for quickly assessing any variation in the beam energy. The figure also shows 95% prediction limits, which represents about ± 0.3 MeV.

The slope of the linear fit indicates the sensitivity of the device for detecting variation in the beam energy. It is clear from Fig. 4 that the device, as we have made, is more sensitive for the I.I. accelerator compared to that for ISOF accelerator. This may be the result of the optimum selection of the thickness of the front plate for the I.I. device.

Because of the increased uncertainty in the beam energy measurement using an aluminium wedge, the usefulness of the device may be slightly limited for low energy. However, this can be easily overcome by more precise energy measurements using improved optical analysis equipment.

5. Conclusion

The data collected for the present work clearly show that such an energy device can also be used for lower energy electrons. It should be borne in mind however that the device should always be calibrated at the same accelerator where it is to be used as a monitoring tool.

The advantages of this device include:

- rugged construction,

- easy on-line use, and
- precision suitable for radiation processing applications.

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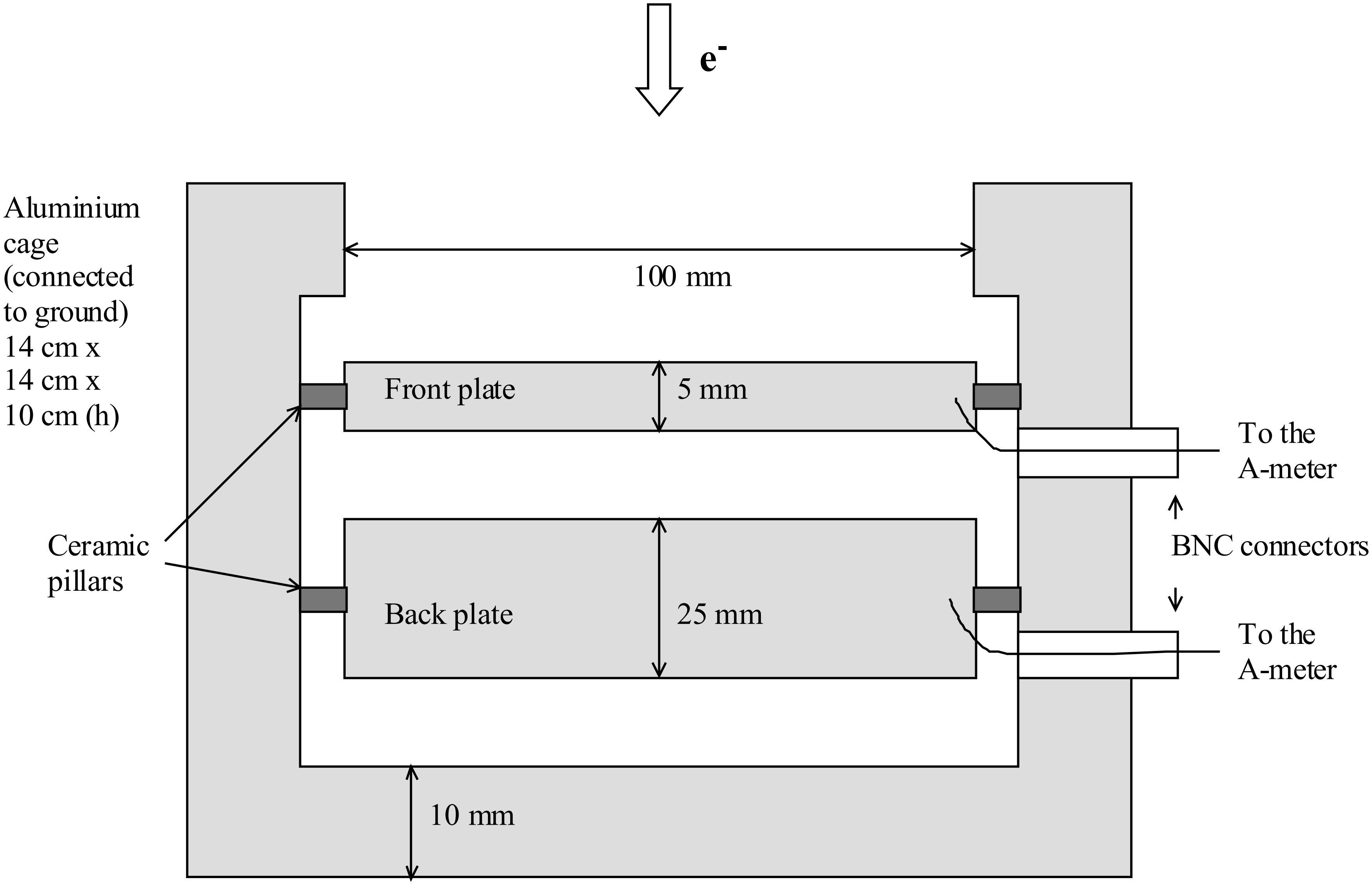
e^-
Aluminium cage (connected to ground) 14 cm x 14 cm x 10 cm (h)
100 mm
Front plate
5 mm
Ceramic pillars
Back plate
25 mm
To the A-meter
BNC connectors
To the A-meter
10 mm

Fig. 1

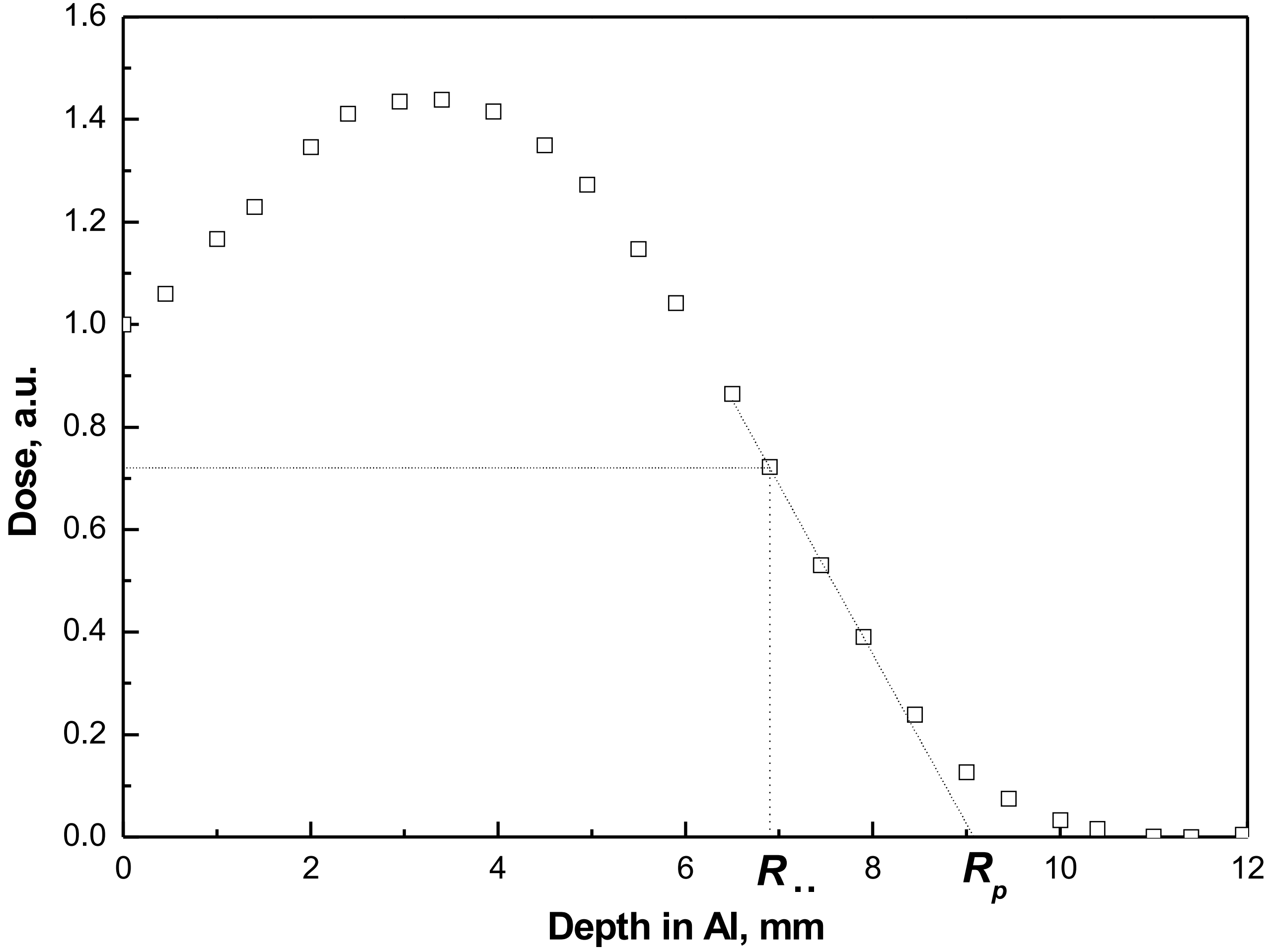

Fig. 2

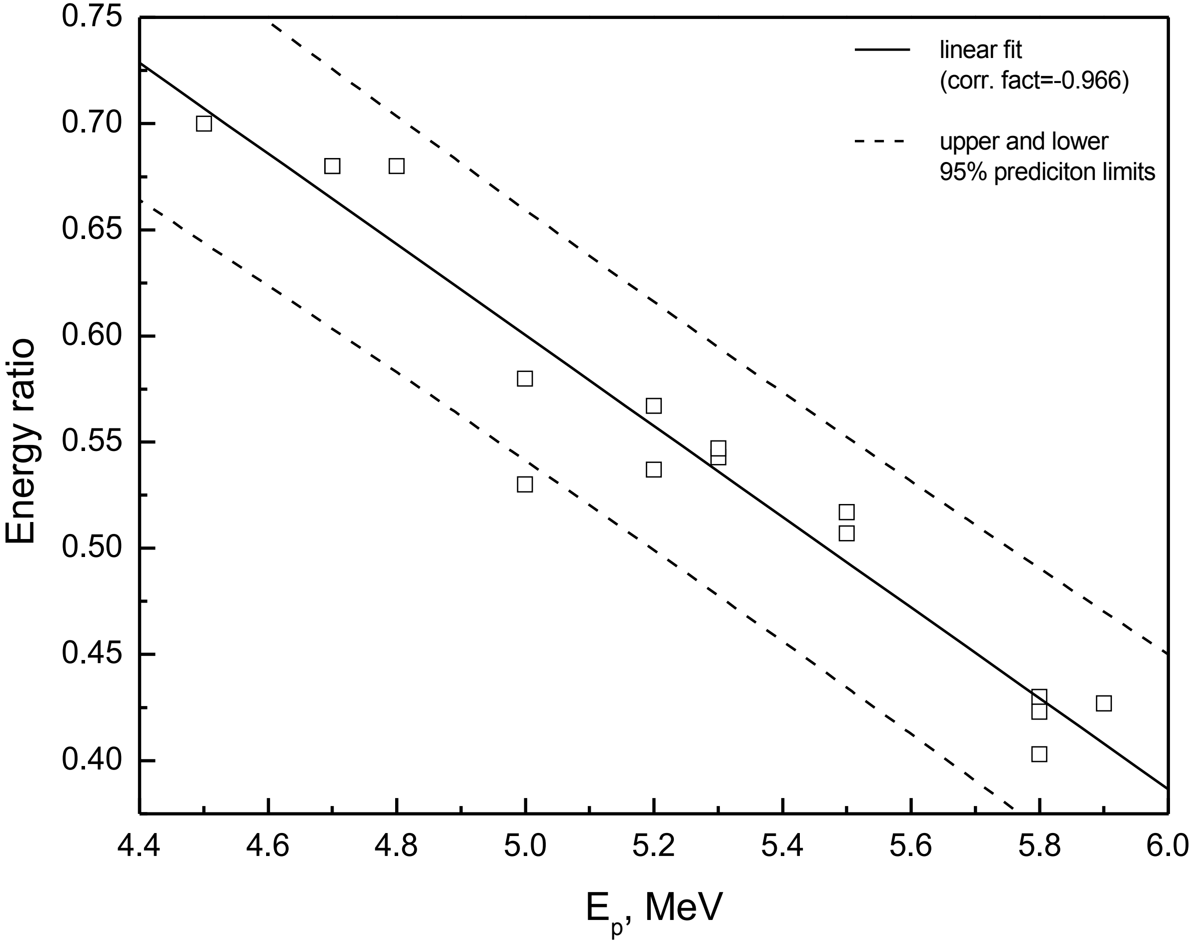
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
Energy ratio
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
E_p, MeV
linear fit
(corr. fact=-0.966)
upper and lower
95% prediciton limits

Fig. 3

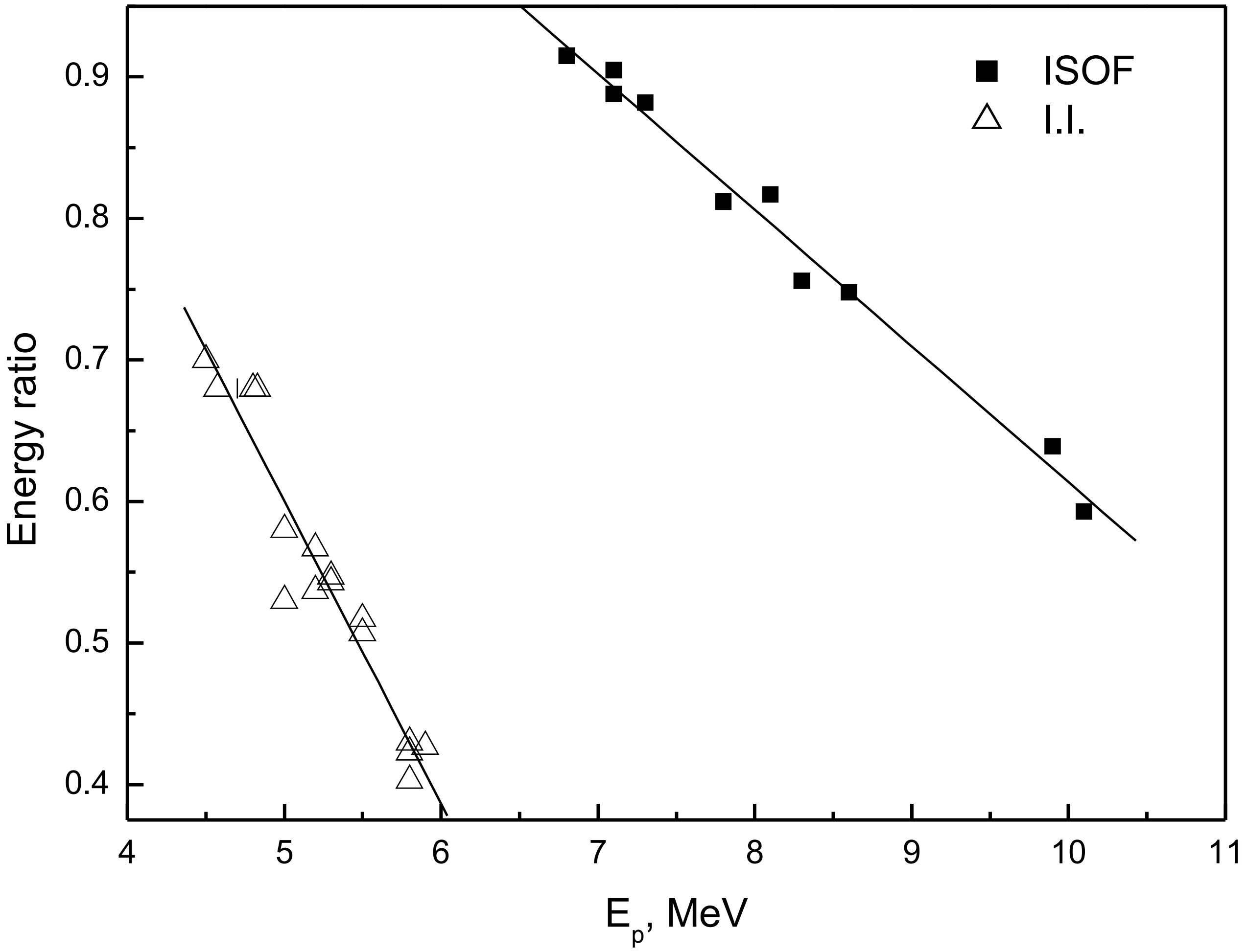

Fig. 4

Table 1.-Experimental data for range parameters, beam energy and energy ratio for different accelerator conditions achieved by varying the beam current as shown here

Current (%)	R_p in Al (cm)	R_{50} in Al (cm)	R_p/R_{50}	E_p (MeV)	Energy ratio (C.V. %)
100	0.88	0.65	1.35	4.7	0.680 (0.0%)
100	0.90	0.70	1.29	4.8	0.680 (1.5%)
100	0.88	0.65	1.35	4.7	0.680 (1.5%)
100	0.85	0.63	1.36	4.5	0.700 (1.4%)
70	0.95	0.73	1.31	5	0.530 (1.9%)
70	1.00	0.78	1.29	5.3	0.543 (1.1%)
70	0.98	0.75	1.30	5.2	0.567 (1.0%)
70	0.95	0.70	1.36	5	0.580 (0.0%)
50	1.05	0.78	1.35	5.5	0.507 (1.1%)
50	1.05	0.80	1.31	5.5	0.517 (1.1%)
50	1.00	0.73	1.38	5.3	0.547 (1.1%)
50	0.98	0.73	1.34	5.2	0.537 (1.1%)
10	1.10	0.83	1.33	5.8	0.403 (2.9%)
10	1.10	0.83	1.33	5.8	0.430 (2.3%)
10	1.10	0.85	1.29	5.8	0.423 (1.4%)
10	1.13	0.85	1.32	5.9	0.427 (1.4%)

Figure Captions

Figure 1. – Cross section view of the energy device.

Figure2. – Typical depth-dose distribution for the I.I. accelerator.

Figure 3. – Correlation between the measured values of the energy ratio and the most probable beam energy (E_p) for I.I. accelerator. The data are from Table 1. The computer generated best linear fit to these data as well as 95% prediction limits are also shown.

Figure 4. – Correlation between the measured values of the energy ratio and the most probable beam energy (E_p) for ISOF and I.I. accelerators. The data for I.I. are from Table 1, and the data from ISOF are from Ref. [1]