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COLLIMATING SYSTEM FOR ELECTRON BEAMS

by

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Electron beams are usually defined by collimators consisting of a diaphragm and a cone. Materials for collimation have been examined at several laboratories (BEATTIE et coll. 1962, LOEVINGER et coll. 1961, SEMPERT 1960, LAUGHLIN et coll. 1953). The cone walls are made of low atomic weight materials such as lucite, aluminium, duralumin or brass; of these lucite possesses the advantage of being transparent. The wall material increases the dose rate due to the increased content of scattered electrons; these contribute to the skin dose and to the superficial part of the central axis depth dose (LOEVINGER et coll. 1961, BRADSHAW & MAYSENT 1964).

Collimation of electrons for radiation therapy involves physical as well as practical problems. Shielding, palpation and tatooing in the region treated are difficult when closed applicators are used; in the head and neck regions, the cones often fail to make good contact with the skin. Physically, it is dose rate, homogeneity, skin dose and the dose distribution at the edges of the field that are influenced by the collimating system.

Improvements in the standard cones have been reported. DAHLER (1964) described a straight lucite tube furnished with a thin layer of metal at the edges

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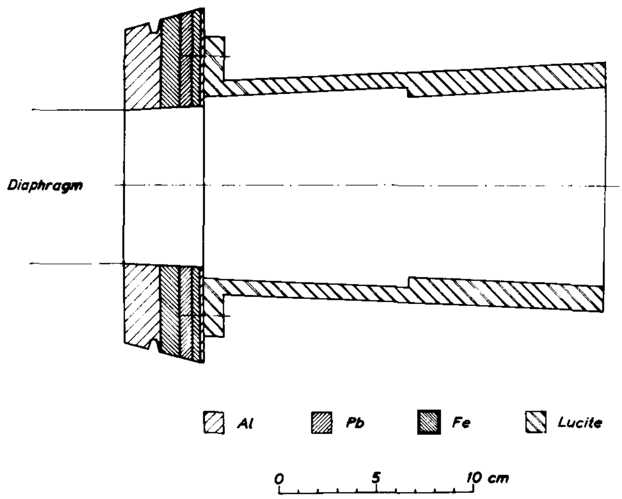


Fig. 1. The BBC standard collimator.

to give a better dose distribution. SVENSSON & HETTINGER (1967) met most of the physical requirements with brass plates defining the field size; they reported that the dose rate increased considerably with a wider aperture in the betatron.

The following work was done on a Brown Boveri Corp., (BBC) betatron, Asklepitron 35.

A standard collimator (Fig. 1) is inserted into a metal box, called 'the master collimator', containing the monitor chamber. The 'sandwich' consisting of 18 mm Al, 10 mm Fe, 5 mm Pb and 5 mm Fe, and the lucite walls converge to a point 110 cm from the edge of the cone. The scattering contribution to the surface may be determined by exposures perpendicular to the beam direction with the films on the surface of the phantom and at the depth of the maximum dose. The relative densities produced in three exposures of six films in this way in a polystyrene phantom appear in Fig. 2 (100 per cent at maximum dose). Sandwich plus cone, sandwich alone and metal frame (3.5 mm Al + 0.5 mm Pb) were used. The metal frame placed in contact with the phantom defined the same field size as the cone but with the maximum aperture in the sandwich. The first two exposures (curve a) have equal density distributions across the beam but the surface density is higher with the cone. The essential collimation is accomplished by the sandwich. The metal frame increases the surface density even more (curve b), but at the depth of maximum dose the beam is well defined by the improved distribution at the margins.

The present design was prompted by experiences with a metal frame defining the field size close to the patient (SVENSSON et coll. 1967). However, the collimation ought to be more easily adapted to the body contours.

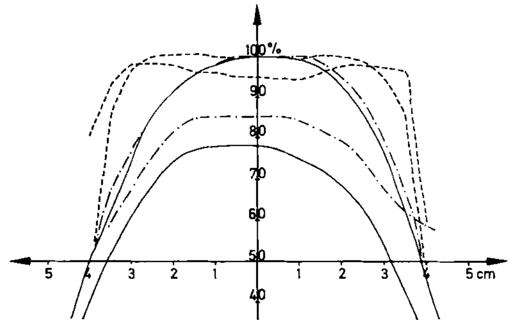


Fig. 2. Relative density of films irradiated at the surface and at depth of maximum dose (100 per cent) for a) original collimating system with (—. —.) and without (—) lucite cone, b) metal frame collimator (- - - -) with the same opening, 8 cm ⌀.

The possibilities of palpation in the field as well as tatooing the field were agreed by the clinicians as being desirable. The effect of improving the dose rate by increasing the aperture has been reported elsewhere (LINDSKOUG & JOHANSSON 1971).

Thirty MeV electrons were used in the determination of transmission and activation. Plates of different materials were placed in front of a polystyrene phantom (20 cm × 20 cm × 30 cm) and irradiated perpendicularly; an ionization chamber of transmission type (LINDSKOUG 1966) was placed at a depth of 3 cm in the phantom. Fig. 3 indicates the relative ion currents against thickness of Al, Pb and lucite, the transmission through Pb and Al equalling that reported by LOEVINGER et coll. (1961). The minimum of bremsstrahlung, mass and geometric extension was the object of the experiment. The most interesting part of the diagram is enlarged in Fig. 4, where some plate combinations are also presented. The combination of 10 mm DAl + 5 mm Fe + 5 mm Pb, was chosen due to its small mass and geometric extension. It permits 8.5 per cent transmission.

A sensitive radiation protection instrument (Jordan, Model AGB-10KG-SR) was used to obtain the relative induced activities in some of the materials of interest. The plates were irradiated with 400 rad. The activation is due to (γ, n) reactions from the generated bremsstrahlung. The Jordan instrument was placed in a test jig, 65 mm from the irradiated metal plate (see Figs 5, 6) and the instrument reading was recorded at predetermined intervals, the recording for brass was taken as 100 per cent. Al and Fe produce small activities that soon decay. The activity of brass has two components, ^{62}Cu ($T_{1/2} = 10.15$ min) and ^{63}Zn ($T_{1/2} = 38.3$ min). Brass is the material that gives highest activity. After a second irradiation, this time with 5 000 rad, the brass plate was found still to have a measurable activity 930 minutes (15.5 h) after irradiation (Fig. 6).

Cumulation of activity appears to be a definite risk only if a collimator of brass be used frequently.

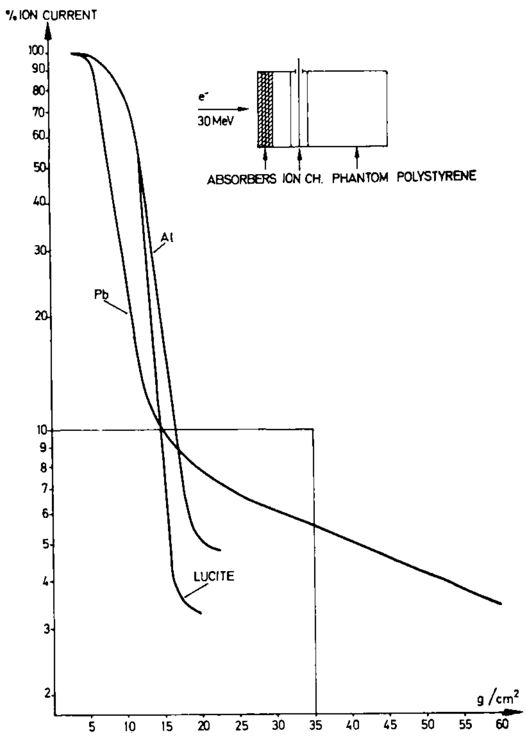


Fig. 3. Relative ionization current against surface thickness of Al, Pb and lucite.

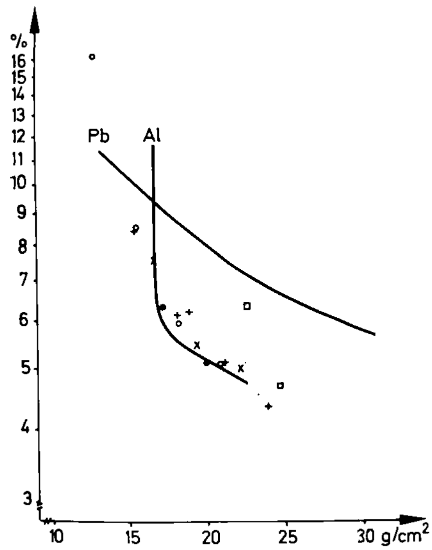


Fig. 4. Relative ionization current against surface thickness of Al, Pb and some combinations of metal plates.

○ Al + Pb, □ Al + Fe + Pb, × duralumin + steel, ● duralumin + Pb, + duralumin + steel + Pb.

Table 1

Collimators and corresponding insets (dimensions in cm)

Collimator	Insets
14×14	14×10, 14×8, 12×12
10×10	10×8, 10×6, 8×8, 6×6
Ø 14	Ø 12
Ø 10	Ø 8
Ø 6	—

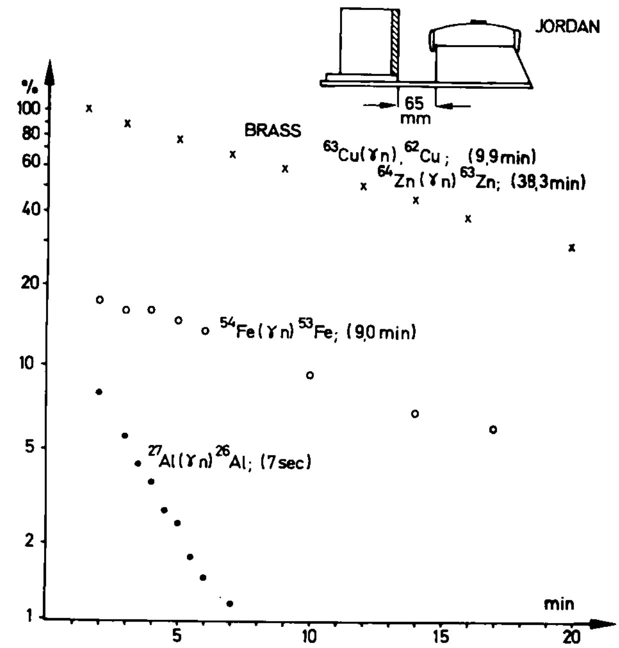


Fig. 5. Set-up and the induced activity in Al, Fe and brass after irradiation (400 rad, 0.35 mR/h) with 30 MeV electrons (t = 0 at end of irradiation).

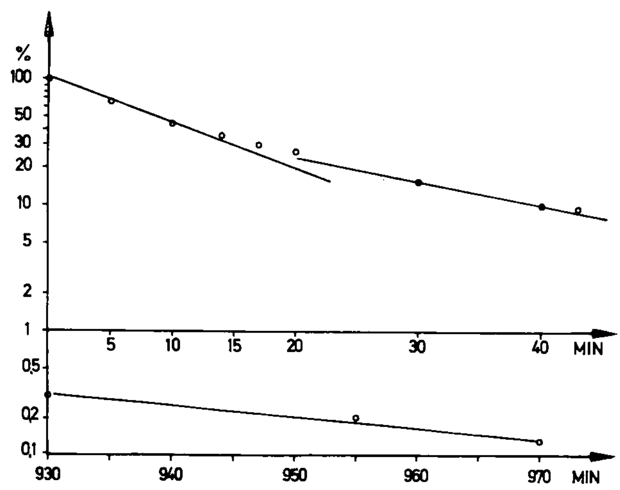


Fig. 6. Induced activity in brass irradiated with 5 000 rad (6.2 mR/h; t = 0 at 5 min after irradiation).

A set of collimators was made with several insets defining the field size as listed in Table 1. The design was as follows. A 2 cm broad frame composed of the chosen metal sandwich and defining the field was made. The leading 30 mm consisted of a 50 mm lucite extension, 5 mm thick, which could be changed

Table 2

Skin dose as percentage of dose at maximum depth

Energy MeV	10	15	20	25	30	35
Skin dose	91	88	92	94	92	92

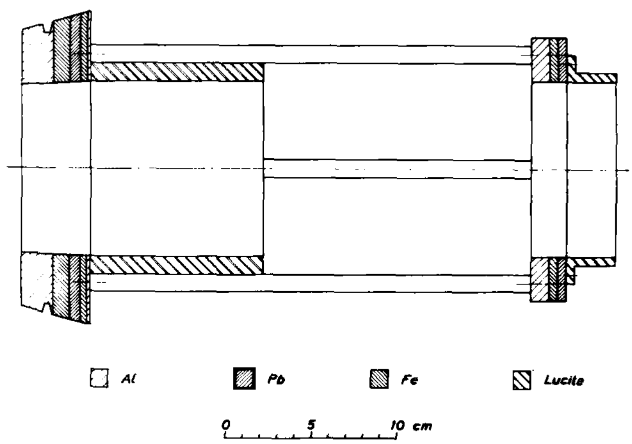


Fig. 7. The new collimator construction for a 10 cm × 10 cm field.

easily and machined to fit irregular surfaces; furthermore the lucite extension would separate the skin and the metal frame, a factor of importance as the frame edge is the source of scattered electrons contributing to the surface dose. Experiments on glancing-angle electron scatter have indicated the presence of small-angle scattering, and independently, of wide-angle scattering (LOEVINGER et coll. 1961).

The collimator defining the field size 10 cm × 10 cm is schematically depicted in Fig. 7. Fifteen and 30 MeV isodose diagrams are collected for comparison with the corresponding diagrams for the standard lucite collimator (Fig. 9). The collimator defining the field-size 14 cm × 14 cm is represented with different insets in Fig. 8.

The density distribution outside the metallic frame in a film exposed at right angles to the beam is depicted in Fig. 10. The density is approximately 17 per cent of that measured within the beam. This effect was due to wide side-scattering from the diaphragm and was eliminated by mounting a lucite screen just in front of the sandwich. A suitable length was experimentally found to be 100 mm; the density decreased to 4.3 per cent. The dose distribution on the surface, inside and outside the radiation field was determined by thermoluminescence dosemeters

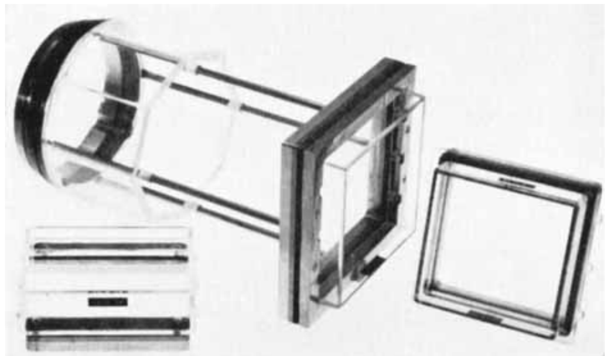


Fig. 8. Collimator, field size 14 cm × 14 cm with two different insets.

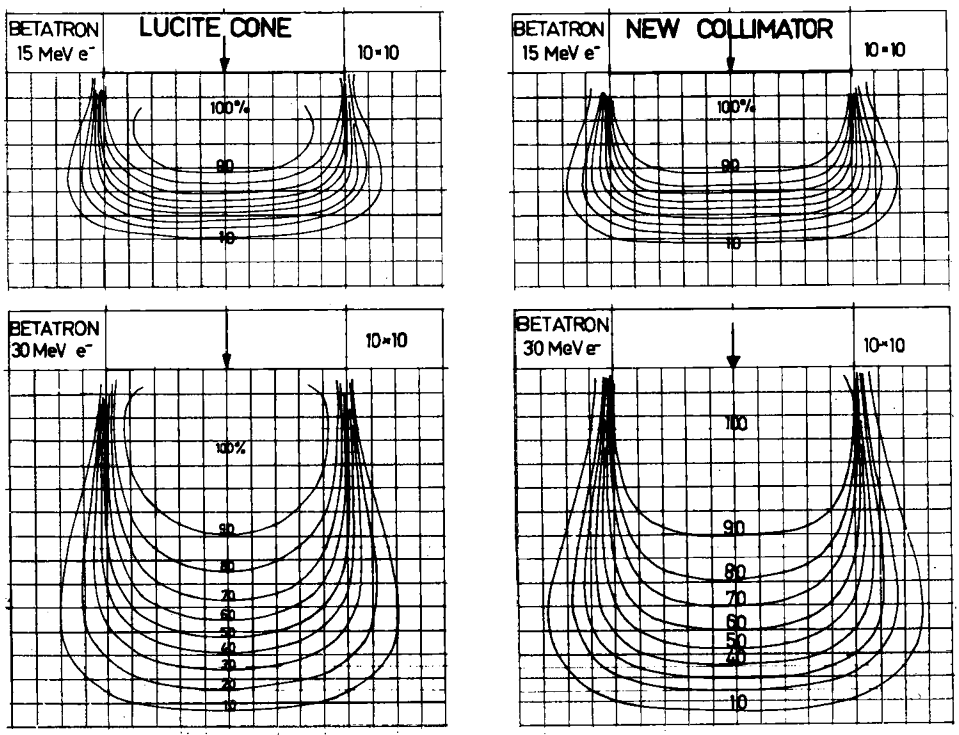


Fig. 9. Comparison of isodose diagrams with a lucite cone and the new collimating system with energies of 15 and 30 MeV; field size 10 cm × 10 cm.

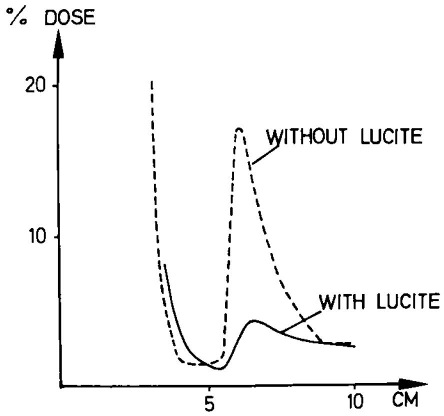


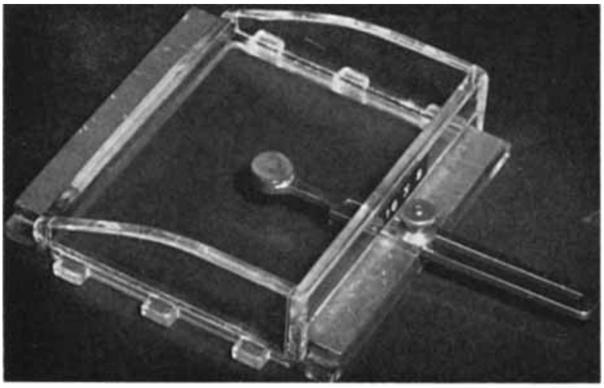
Fig. 10. Edge effect investigations.

(extruded LiF rods, Harshaw). These were placed at the surface of a lucite plate with grooves to fit the rods and the absolute and the relative doses at the surface and at the maximum dose were determined; contamination of scattered low energetic electrons outside as well as inside the frame were evident. Representative skin-dose values are given in Table 2. The surface dose measurements were confirmed by films and the agreement with the LiF was within ± 2 per cent. The standard error for these measurements were kept within ± 2 per cent by individual calibration and track of the LiF dosemeters.

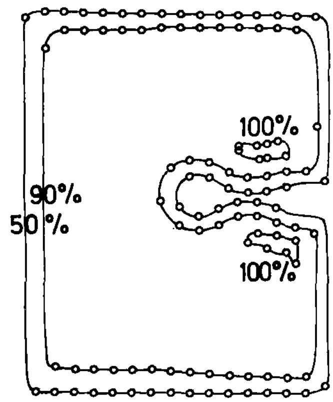
A brief investigation concerning the use of paraffin as blocking material in electron beams has been given by Dahler (1968). He concluded that lead is far superior to paraffin and other equivalent materials in this respect; special protective devices of lead have been designed to be attached to the collimator frames.

An urethra protection block, 12 mm ⌀ and 5 mm thick, was designed for use in the treatment of carcinoma of the vulva so as to be conveniently arranged in the field (Fig. 11 a). The corresponding isodensity distribution in a film exposed perpendicular to the beam appears in Fig. 11 b. The film was measured with a semi-automatic isodensity recorder system (Sköldborn 1966).

The new collimators have the following advantages in comparison with those of the standard type (lucite tubes): (1) higher dose rate, (2) better dose gradient at the edges of the beam, (3) easier set-up, with the possibility of marking and palpating in the field, (4) they can be machined to fit various body contours, (5) the field sizes are easily changed by insets and, (6) beam shaping blocks may easily be attached. The collimators have been used routinely for one year. No problems have arisen during this time and the clinicians and



a



b

Fig. 11. a) Protecting device for the urethra. b) Accompanying field distribution at depth of maximum dose. Energy 20 MeV.

the radiotherapy assistants working with them find them practical and easy to handle.

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SUMMARY

A new collimating system for electron beams with which extensive measurements including those of induced activity, skin dose and scatter conditions have been performed is described. This appears to constitute a general improvement on the standard cones as regards dose distribution and dose rate, achieved by means of a field defining diaphragm of a special sandwich type.

ZUSAMMENFASSUNG

Ein neues Einblendungssystem für Elektronenstrahlenbündel wird beschrieben. Umfassende Messungen, mit Einschluss solcher der Sekundärstrahlung, der Hautdosis und der Streustrahlung wurden vorgenommen. Es zeigte sich, dass die neue Blende dem bisher gebräuchlichen Tubus hinsichtlich Dosenfluss und Dosenverteilung überlegen ist. Dieses Resultat wird durch eine besser konstruierte Blende, die aus meheren Schichten besteht, erreicht.

RÉSUMÉ

Les auteurs décrivent un nouveau système de collimation pour les faisceaux d'électrons qui a permis des mesures variées, y compris la mesure de l'activité induite, de la dose à la peau et des conditions de dispersion. Ce collimateur paraît constituer un perfectionnement général par rapport aux cônes standards en ce qui concerne la distribution de dose et le débit de dose, obtenu au moyen d'un diaphragme délimitant le champ d'un type spécial, en sandwich.

REFERENCES

Beattie J. W., Tsien K. C., Ovadia J. and Laughlin J. S.: Production and properties of high energy electrons for therapy. Amer. J. Roentgenol. 88 (1962), 235.

Bradshaw A. L. and Maysent A. M.: Physical aspects of electron therapy using the 15 MeV linear accelerator. Brit. J. Radiol. 37 (1964), 219.

Dahler A.: Effect of collimator-shape on electron depth dose curve. *In*: Proceedings of the international symposium on high energy electron, Montreux, p. 98. Springer Verlag, Berlin 1964.

— Blocking of fields in electron beam therapy. *In:* Proceedings of the Fifth Nordic Meeting on Clinical Physics. Saltsjöbaden, Sweden 1968.

Laughlin J. S.. Ovadia J., Beattie J. W. et coll.: Some physical aspects of electron beam therapy. Radiology 60 (1953), 165.

Lindskoug B. och Johansson K. A.: Inmätning av 35 MeV betatronen vid Sahlgrenska sjukhuset i Göteborg. (In Swedish.) *In:* Proceedings of the Fourth Nordic Meeting on Clinical Physics, Hanko, Finland (1966), 72.

— — Collimator and scattering foil for 10—20 MeV electrons. Acta radiol. Ther. Phys. Biol. 10 (1971), 21.

Loevinger R., Karzmark C. J. and Weisbluth M.: Radiation therapy with high-energy electrons. Radiology 77 (1961), 906.

Sempert M.: New developments in high energy electron beam therapy with the 35 MeV Brown Boveri Betatron. Radiology 74 (1960), 105.

Sköldborn H.: En ny semiautomatisk isosvärtningsskrivare. (In Swedish.) *In:* Proceedings of the Fourth Nordic Meeting on Clinical Physcis. Hanko, Finland, (1966), 67.

Svensson H. and Hettinger G.: Influence of collimating systems on dose distribution from 10 to 35 MeV electron radiation. Acta radiol. Ther. Phys. Biol. 6 (1967), 404.