VARIABLE ELECTRON COLLIMATOR FOR THE MEVATRON 77

DESIGN AND DOSIMETRY

by

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Introduction

The two primary types of electron beam collimation for field shaping are 1) the use of a set of fixed collimators which accept secondary field shaping in the form of low melting point lead alloy inserts, and 2) the use of a variable electron collimator with a mechanism for accepting a blocking tray. The former is useful in that the blocks for highly irregular fields need not be reconstructed each day. However, it is necessary to constantly be changing out inserts and cones, even if a series of regularly-shaped rectangular fields are desired, as is frequently the case for treatment of the chest wall post mastectomy. Siemens has made an effort to make both collimator options available to its users. However, our institution feels that the existing variable collimator marketed by Siemens could be designed to be more clinically useful, particularly for chest wall irradiation.

Table I summarizes the pertinent physical properties of the existing variable collimator and compares them with the proposed features of the new variable collimator. First, the increased range in field sizes from 6 x 6 - 20 x 20 cm to 3 x 3 - 25 x 30 cm would allow the treatment of strips less than 6 cm width, which are frequently encountered in head and neck treatment, and the treatment of large fields up to 25 x 30 cm, which are frequently encountered in chest wall irradiation.

Second, symmetric jaw movement was preferred by our therapist in order to assure that the patient was treated with identical fields each day. Also, there was the desire to be consistent with the commercial treatment planning algorithms which assume symmetric fields. Third, the air gap was increased from 5 cm to 10 cm in order to allow the trimmer bars to accept a tertiary blocking tray and still have sufficient air gap to prevent collimator-patient collision. Finally, there was a desire to reduce the weight of the collimator which was required for the radiotherapy technologist to handle. Increasing the range of field sizes available required heavier collimators; however, overall weight reduction was accomplished by making removable secondary collimators (trimmers) and by having the photon jaws track synchronously with the electron collimators. The purpose of this paper will be to discuss the factors considered in the engineering design and the dosimetry measurements performed on a prototype.

Engineering Design

A variety of factors must be simultaneously considered in the design of a variable electron collimator. The collimator had to be designed to provide a uniform dose distribution on the patient with a sharp penumbra and insignificant collimator leakage. The geometry and design had to be optimized for minimal weight. From a user's point of view, it had to have good mechanical movements and be safe.

Any machine modifications necessary to install the new collimator had to be considered. Finally, all aspects of the collimator need to be considered in order to evaluate its clinical practicality.

The first step was to select an appropriate type and thickness of collimating material. Brass was selected as the material of choice because of its high density, intermediate atomic number (to minimize bremsstrahlung dose, i.e. less than that from lead), its durability, and its ease in machining. The thickness of brass was estimated from the transmission curve plotted in Figure 1. Transmission is defined as the ratio of dose behind brass in a plastic phantom to dose at the depth of maximum with no brass. The maximum dose with brass present is assumed to be at the surface of the phantom (Khan, et al., 1981, Meyer et al., 1984). The plot shows that 1 cm of brass is adequate to reduce the dose to approximately 15%. Based on this data we have selected 1/2" brass, as it should be useful for electron energies as great as 22 MeV, which is near the maximum energy which could be extracted from the existing waveguide and beam transport system of the Mevatron. It should be pointed out that these measurements were made with a large field geometry and with the beam in direct contact with the phantom. In the final collimator design, the brass will be considerably above the skin so that any electron transmitted (e.g. in tail of distribution) would have only a small chance of striking the patient since they would be emitted with such large angles.

Also, since the portion of the trimmer actually being struck by electrons is small, the bremsstrahlung dose will be less.

The next step was to deduce the optimal placement and width of the collimator jaws. Figure 2 illustrates the principle used for this determination. If a uniform electron fluence passes through the aperture of the upper collimator, then the profile at some distance downstream has a penumbra with a characteristic shape. The width of the penumbra is governed by the "sigma" of an electron pencil beam which propagates from the upstream to the downstream collimator. Equations used to calculate sigma resulting from air scatter are given in Figure 4. The downstream collimator needs to then be designed such that its outside edge is 2.05 outside of the edge projected by the upstream collimator (see dashed line) in order to minimize beam leakage around the edge of the collimator. The downstream collimator's inside edge needs to be designed so that it is 1.64 inside of the projected edge in order to ensure both a uniform beam and a sharp penumbra to either the patient below or the next beam collimator.

On the Mevatron, the electron beams first see the photon jaws which are a significant distance above the patient. Due to multiple scattering in air, the penumbra cast by them is quite large and an exceptionally broad trimmer bar near the patient would be required to restore the beam penumbra.

Therefore, an intermediate set of electron trimmers is inserted as depicted in Figure 3. Note that the left half of the figure represents the lower jaws and the right side the upper jaws, and that the divergence of the beam is now considered. The location of the photon jaws is taken to be the most downstream edge for the purpose of calculation. The primary electron jaws are located just below the accessory tray, as the closer they can be placed to the photon jaws, the lighter their weight can be made. Putting them too close to the upper jaws would again require the secondary electron trimmers to become too large, but that is not a problem with the present geometrical constraints. The resulting size of the secondary electron collimators is in fact large enough for mechanical integrity, but small enough so as to not interfere with patient setup.

If the photon jaws are set at a fixed field size (as is done with the present variable collimator and fixed applicators), then one of two collimator solutions are possible. First, the primary electron collimator can be made an optimal size and fixed in space. The secondary electron collimator would then have to translate to define field size, and would have to be made extremely wide so that, for the widest field, its inner edge is in the position relative to the primary collimator as shown in Figure 3 and that for the narrowest field, its outer edge is in the position relative to the primary collimator as shown in Figure 3.

This would make the secondary electron collimator quite wide, becoming both heavy and physically interfering with patient setup; this would be unacceptable. A second solution would be to constrain the primary and secondary electron collimators to open and close in unison. This allows a narrow secondary electron collimator and is the philosophy of the existing variable electron collimator. Again, the primary electron collimator now has to be wide enough to prevent leakage around its edge as the field size is closed to its smallest field size since the photon jaws are fixed. This explains why the 30 lb. weight of the existing variable collimator and the 6-20 cm wide field sizes were a trade-off. To increase the range in field sizes would have increased the weight of the collimator.

Our proposed solution to the problem was to have the photon jaws to open and close in unison with the primary and secondary electron collimators. This allows both electron trimmers to be made their minimal width. Because mechanical coupling of the electron collimators to the photon jaws is not possible, they will be coupled electronically, requiring a modification to the existing Mevatron. The optimal solution for collimator design is shown in Figure 3. The primary electron collimators are as close as possible to the source, and the secondary electron trimmers are as close as desired to the 100 cm treatment SSD, allowing a 10 cm air gap to accommodate a tertiary blocking tray and patient clearance.

Figure 4 is a summary of the design calculation sheet used to determine the electron collimator widths. The purpose of the sheet was to determine the necessary sigmas for 6 MeV electrons, a minimal energy where sigma is the greatest. The width of the electron collimators was subsequently verified by placing strips of film above the primary and secondary electron collimators and verifying that they were properly intercepting the penumbra from the photon collimators and primary electron collimators respectively. This was done for both the upper and lower sets of collimators, and the verifications for the upper sets of collimators for 7 MeV electrons are shown in Figures 5 and 6.

The resulting engineering input was then used as a basis for the Siemens' engineers to design and prototype variable collimator, which is picuted in Figure 7A with secondary trimmers attached and Figure 7B with them removed. The secondary trimmers were made removable in order to minimize the weight which a radiotherapy technologist must handle. The resulting collimators then met our design goals of having field sizes variable from 3 x 3cm to 25 x 30cm and the weight of the main frame of the collimator (excluding secondary trimmers) being less than 20 lbs. One advantage to having removable secondary collimators is that a second set can be made available for field sizes less than 10 x 10cm which would be useful in head and neck treatment.

Dosimetry Evaluation

The prototype was then studied by performing dosimetry measurements at 7, 12, and 18 MeV. The field size was varied, and the photon jaws were always set to a field size 10 cm larger than that of the electron collimator at the 100 cm SSD. For a field size of 25 x 30 cm, the photon jaws were set to 35 x 40 cm. (Those Mevatrons limited to a 35 x 35 cm photon jaw might be limited to a 25 x 25 cm electron field.) Depth doses, off-axis ratios, and output for a variety of field sizes were measured.

Figure 8 compares measured isodose curves for a 10 x 10 cm field size at 7 and 18 MeV, using the prototype (new) variable collimator with those produced by the existing (old) one. Note the near-perfect agreement in depth dose. The penumbra, of course, is slightly greater for the new collimator because the air gap has been increased. At the higher energies, the air gap has less influence on the penumbra, particularly at the deeper depths, as shown by the comparison.

Beam profiles were measured for the maximum field size, 25 x 30 cm, at the depth of maximum dose at 7, 12, and 18 MeV as shown in figures 9, 10, and 11, respectively. Each figure plots the off-axis ratio along both major axes and the diagonal of the field. All measurements were made in the "magnetic bend" plane by rotating the collimator head.

Results showed good flatness and a sharp penumbra. There was some problem with the symmetry of the flatness for distances greater than 25 cm from the central axis, which is shown on each curve by using a dashed line to symmetrically reflect the profile. The decrease of the magnitude of the effect with increasing energy indicates that it might be caused by assymmetric beam scatter. At this point in time, we have not isolated the cause.

Although there are only minor differences in the dose distributions created by the new variable collimator with respect to the previous collimator, there are more significant differences in the field size dependence of output. This is because the primary photon jaws are moving with the electron collimators, which results in more variation in output with field size than the existing variable collimator. The dosimetry for this type of collimation system has been discussed in the literature by Mills, et al (1981). Figure 12 compares the field size dependence of output at 7, 12, and 18 MeV. The higher energy has less field size dependence due to its lower angular scattering power.

Summary

This report has outlined the engineering design of a new variable electron collimator for the Mevatron electron beams. Preliminary dosimetry measurements have been made and indicate that it should be feasible to meet design criteria. The new collimator would have a field size variable from 3 x 3 to 25 x 30 cm, symmetric jaw movement, a 10 cm air gap to the 100 cm SSD to allow a tertiary blocking tray, and a weight of less than 20 lbs. These features are expected to increase the range of clinical usefulness of the variable collimator by allowing field dimensions greater than 20 cm in chest wall irradiation, field dimensions less than 6 cm in head and neck treatment, and irregular field shaping using the tertiary blocking tray. These increased capabilities are expected to increase patient throughout by minimizing the need to treat with the fixed field applicators. Finally, the decreased weight should provide ease of handling for the Radiotherapy Technologist.

The dosimetry presented in this paper represents only a sample of that actually measured that required for final patient commissioning. It does, however, confirm the collimator design criteria and provides data to compare with the existing variable collimator.

There appears to be 1) no significant change in depth-dose; 2) minor changes in off-axis ratios as the penumbra width is greater due to the increased air gap, particularly for the lower energies and shallow depths; and 3) significant changes in the field size dependence of output. It would, therefore, be necessary to remeasure a significant amount of dosimetry data prior to clinical use.

The variable collimator will be inserted into the existing accessory tray slot. The Mevatron will require modifications in order to electronically couple the photon jaws and electron collimator so that they track synchronously.

Acknowledgements

The authors would like to acknowledge Robert S. Fields, M.D., whose experience in electron radiotherapy defined the need and specification of a new variable electron collimator for the Mevatron.

References

1. F. Khan, B. Wener, and F. Diebel, Med. Phys. 8, 712 (1981).

2. J. A. Meyer, J. R. Palta, and K. R. Hogstrom, Med. Phys. 11, 670 (1984).

3. M. Mills, K. Hogstrom, and P. Almond, Med. Phys. 9, 60 (1982).

Table I

Comparison of Existing with New Variable Electron Collimator

	Existing Variable Collimator	New Variable Collimator
Field Size	6x6 - 20x20 cm	3x3 - 25x30 cm
Jaw Movement	Asymmetric	Symmetric
Air Gap to Isocenter	5 cm	10 cm
Tertiary Blocking Tray	No	Yes
Weight	30 lbs	20 lbs (removable trimmers)

DOSE BEHIND BRASS SHIELDING

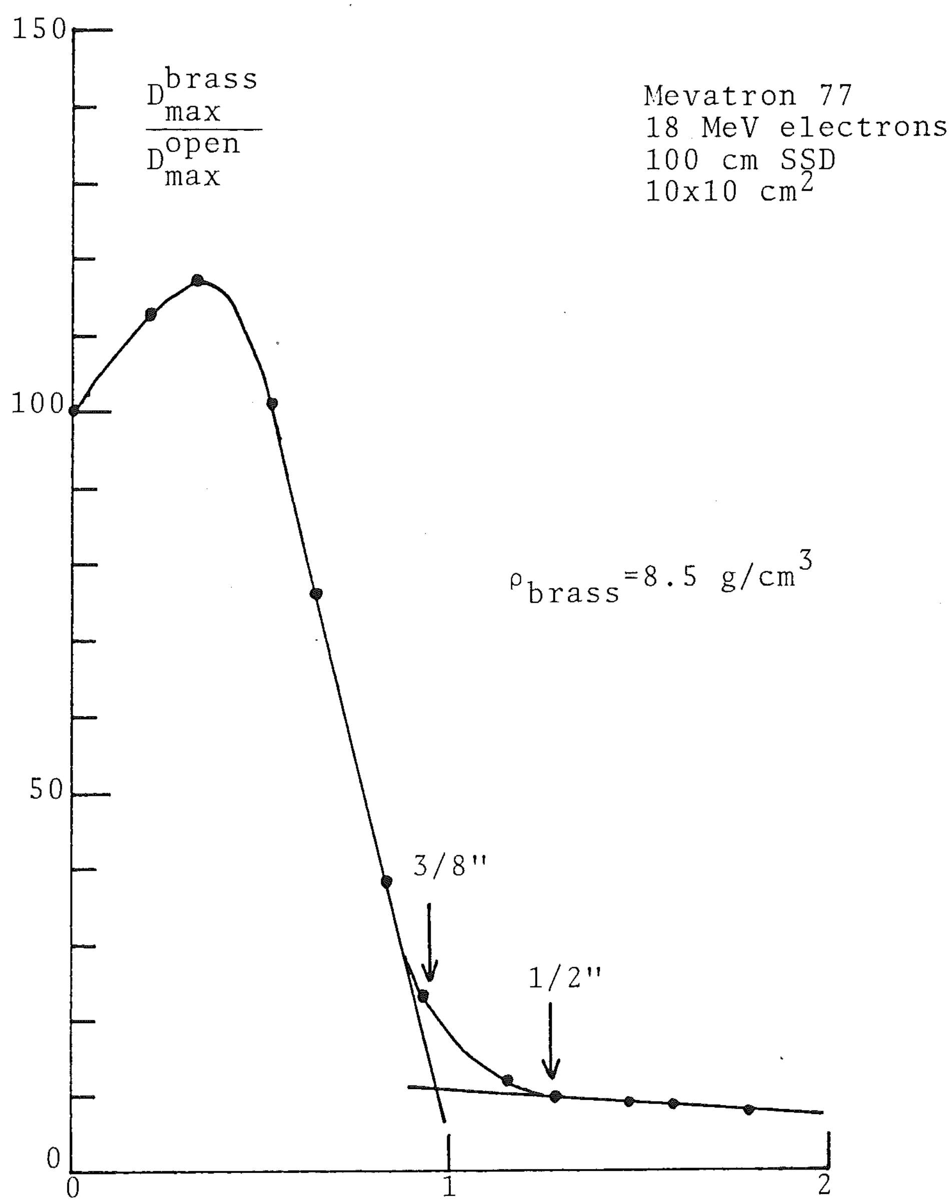

Figure 1

ELECTRON COLLIMATOR DESIGN CONCEPT

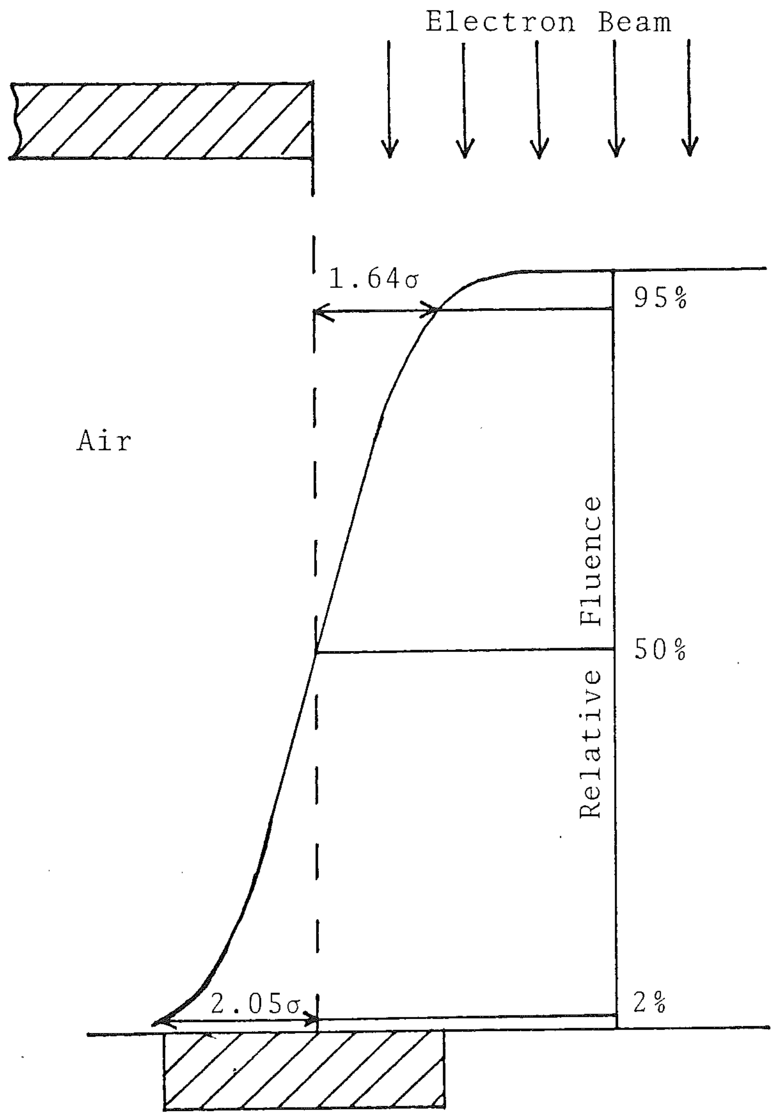

Figure 2

MEVATRON 77 VARIABLE ELECTRON COLLIMATOR

SCHEMATIC OF COLLIMATOR GEOMETRY

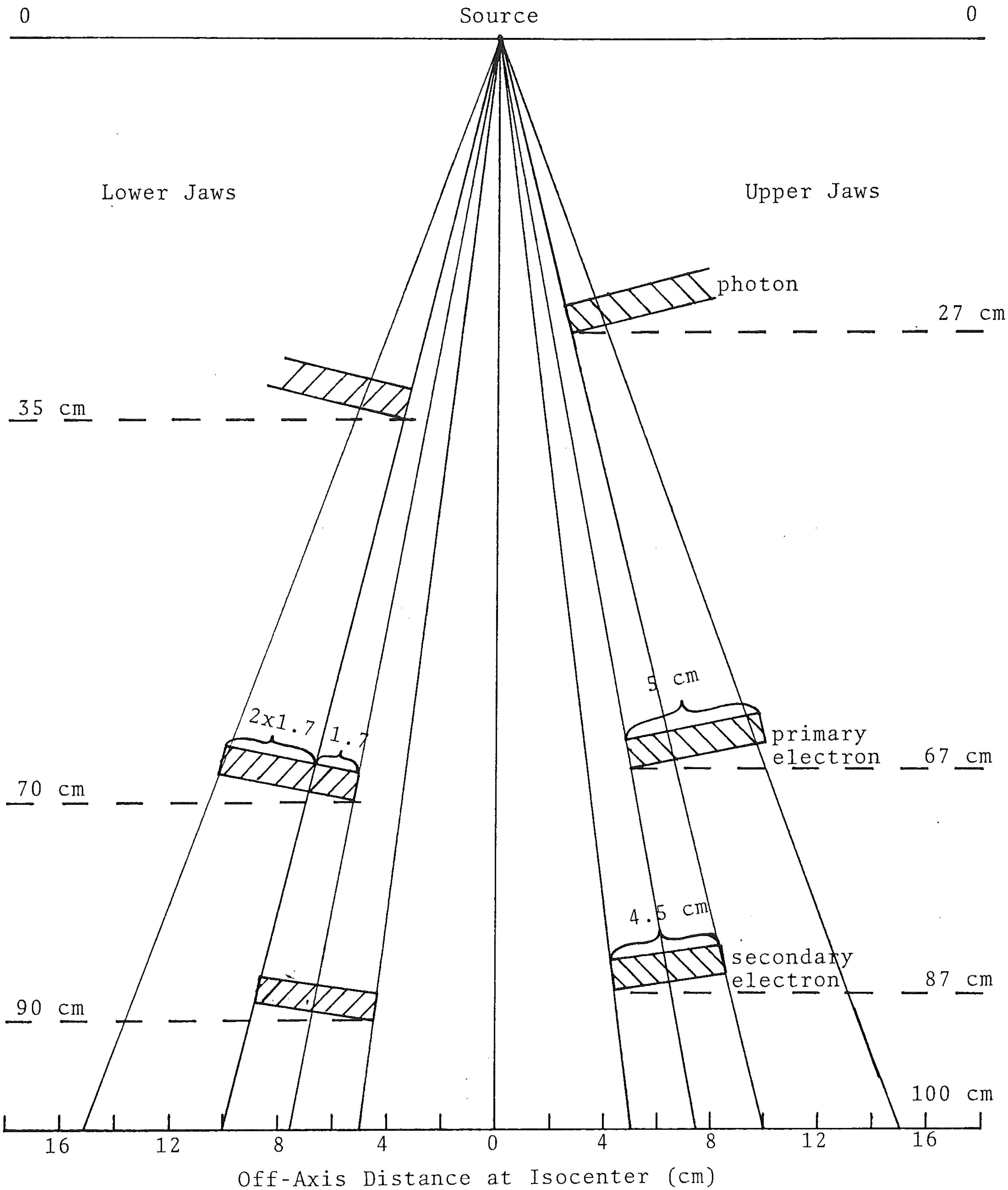

Figure 3

COLLIMATOR DESIGN SHEET

Plan: Mevatron 77 Variable Energy Collimator Design

description	distance from source, Z_i(cm)	Z_{i-1} (cm)	σ_x(cm)*	comments
photon jaws	35	---	---	lower jaws
primary e⁻	70	35	1.7	
secondary e⁻	90	70/35	1.1/3.1	
SSD	100	90	0.6	
photon jaws	27	---	---	upper jaws
primary e⁻	67	27	1.3	
secondary e⁻	87	67/27	1.1/3.4	
SSD	100	87	0.7	

Notes: 2% - 50% $\approx 2.05\sigma$ 50% - 90% $\approx 1.28\sigma$

5% - 50% $\approx 1.64\sigma$ 10% - 90% $\approx 2.56\sigma$

$$* \quad \sigma_x^2 = \left(\frac{d\sigma^2}{dZ}\right)_{air}^{E_o} \cdot (Z_i - Z_{i-1})^2 \cdot \quad \frac{Z_{i-1}}{8} + \frac{(Z_i - Z_{i-1})}{6}$$

$$\left(\frac{d\sigma^2}{dZ}\right)_{air,STP}^{E_o = 6MeV} = 2.41 \times 10^{-4} \text{ radian}^2/\text{cm} \qquad \text{ICRU 21}$$

Figure 4

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VERIFICATION OF NEW VARIABLE ELECTRON COLLIMATOR JAWS

25 x 25 cm PHOTON JAWS; 15 x 15 xm ELECTRON TRIMMERS

UPPER PRIMARY TRIMMERS (67 cm)

Mevatron 77 7 MeV

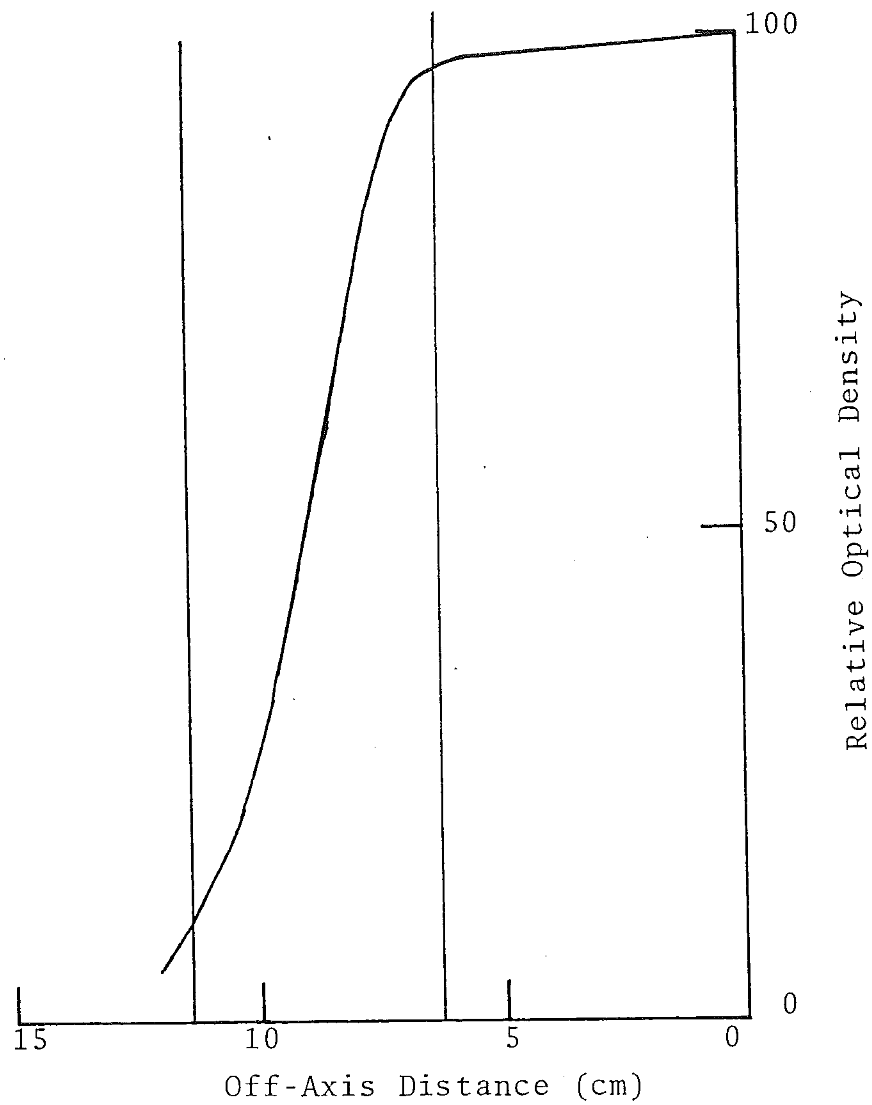

Figure 5

VERIFICATION OF NEW VARIABLE ELECTRON COLLIMATOR DESIGN

25 x 25 cm PHOTON JAWS, 15 x 15 cm ELECTRON TRIMMERS

UPPER SECONDARY TRIMMERS (87cm)

Mevatron 77 7 MeV

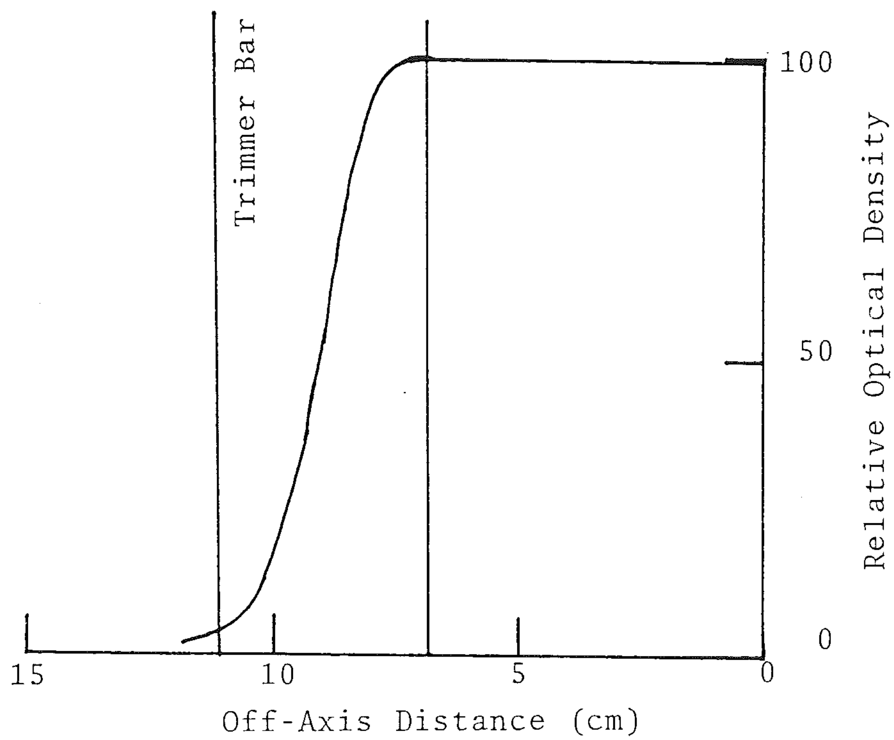

Figure 6

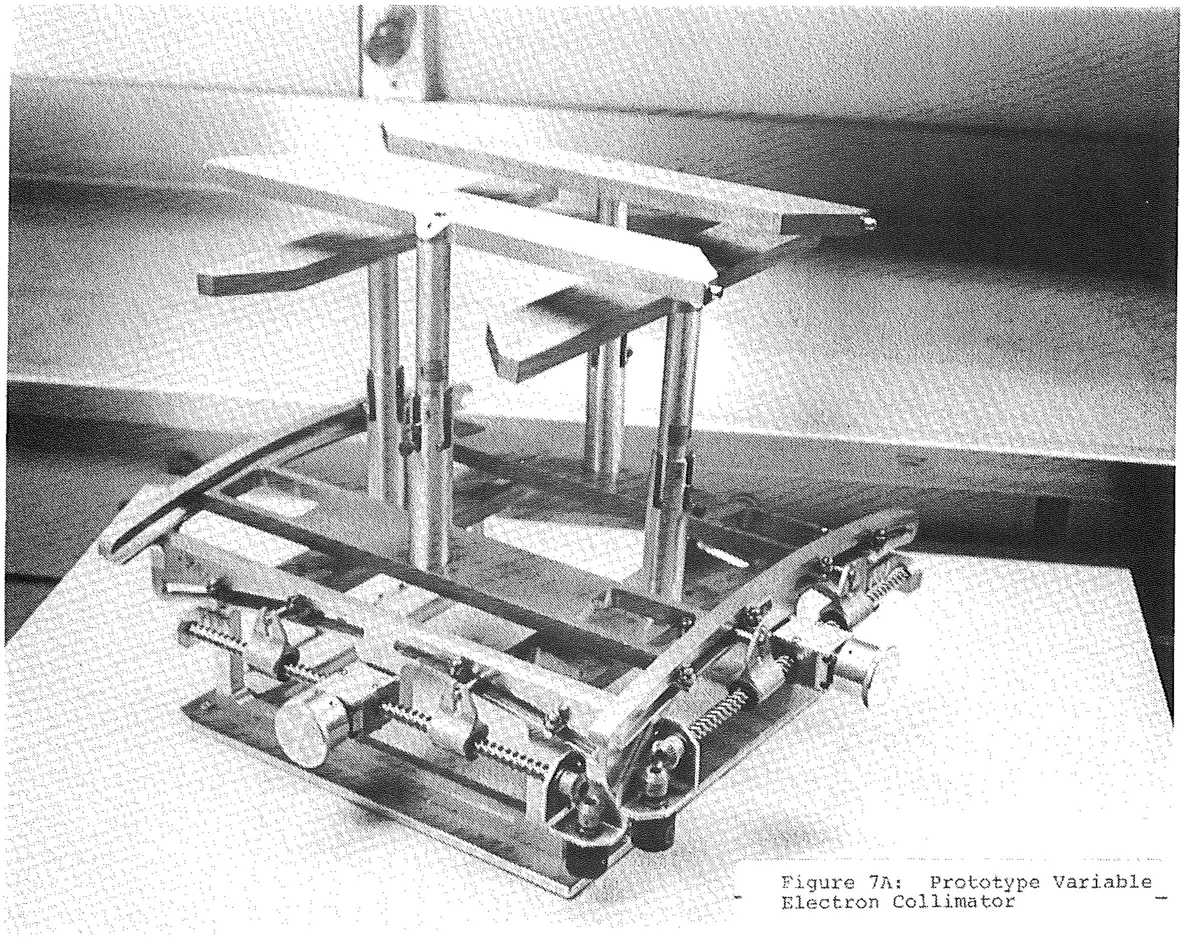

Figure 7A: Prototype Variable Electron Collimator

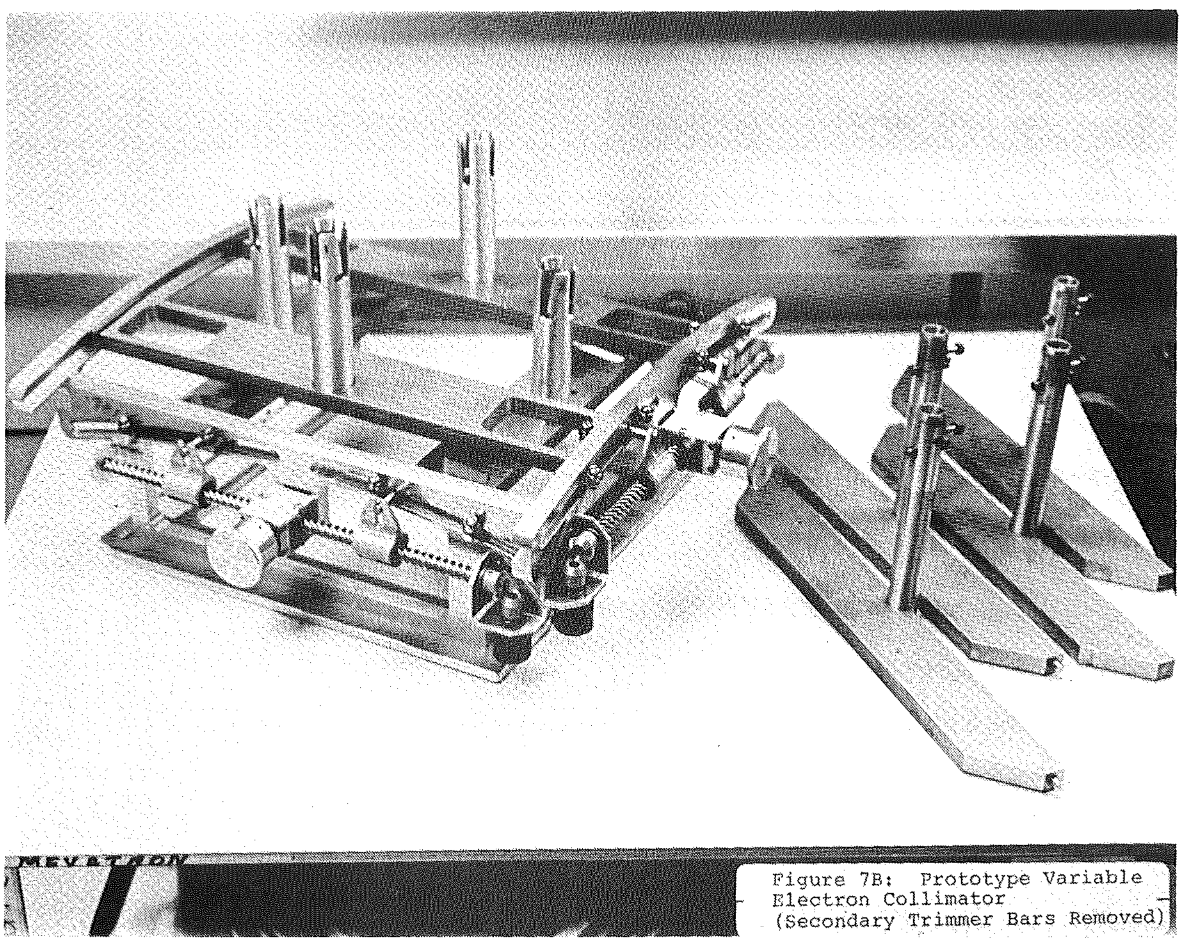

Figure 7B: Prototype Variable Electron Collimator (Secondary Trimmer Bars Removed)

MEVATRON 77 ISODOSE CURVES, 10 x 10 cm^2, 100 cm SSD

COMPARISON OF NEW AND CURRENT VARIABLE ELECTRON COLLIMATOR

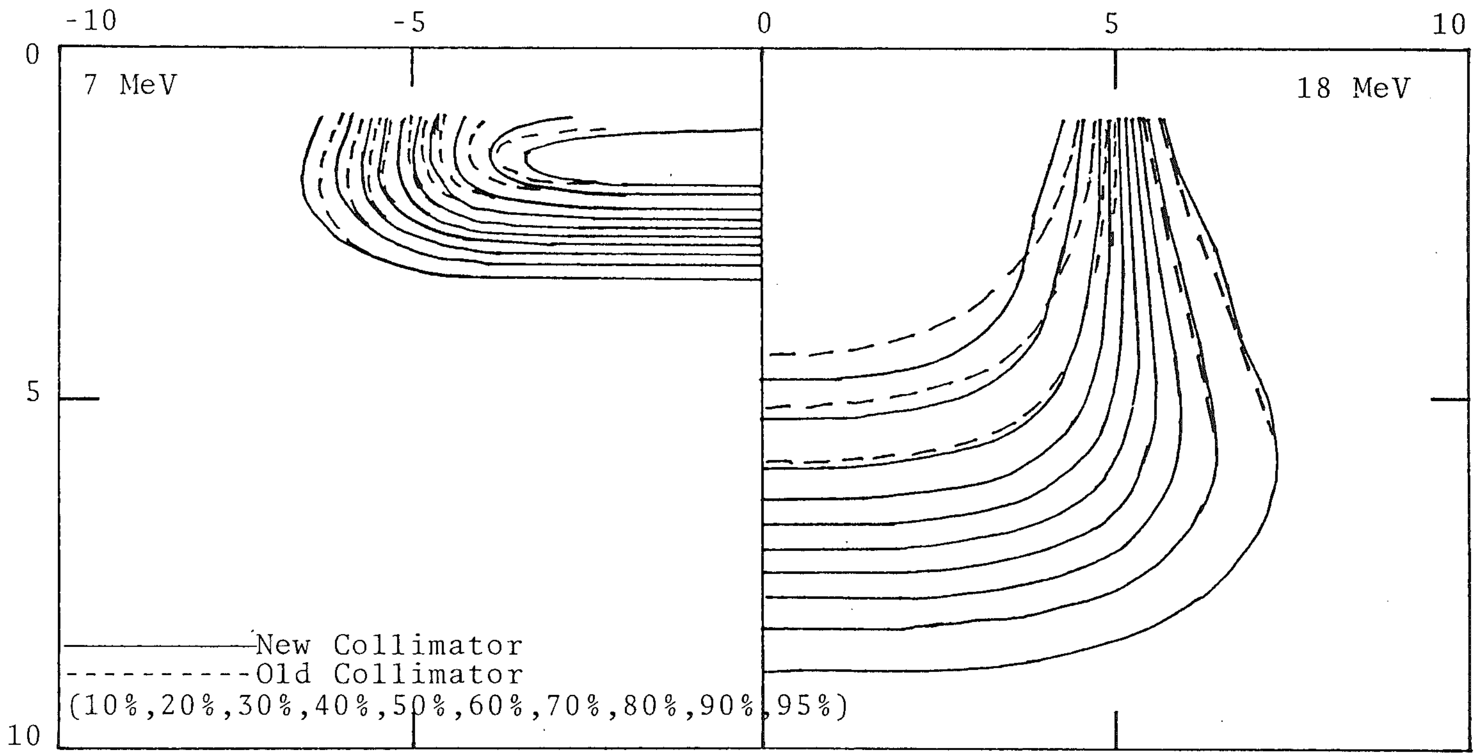

Figure 8

MEVATRON 77 NEW VARIABLE ELECTRON COLLIMATOR

Off-Axis Ratios 7 MeV

100 cm SSD, 25 x 30 cm^2, depth = 1.5 cm

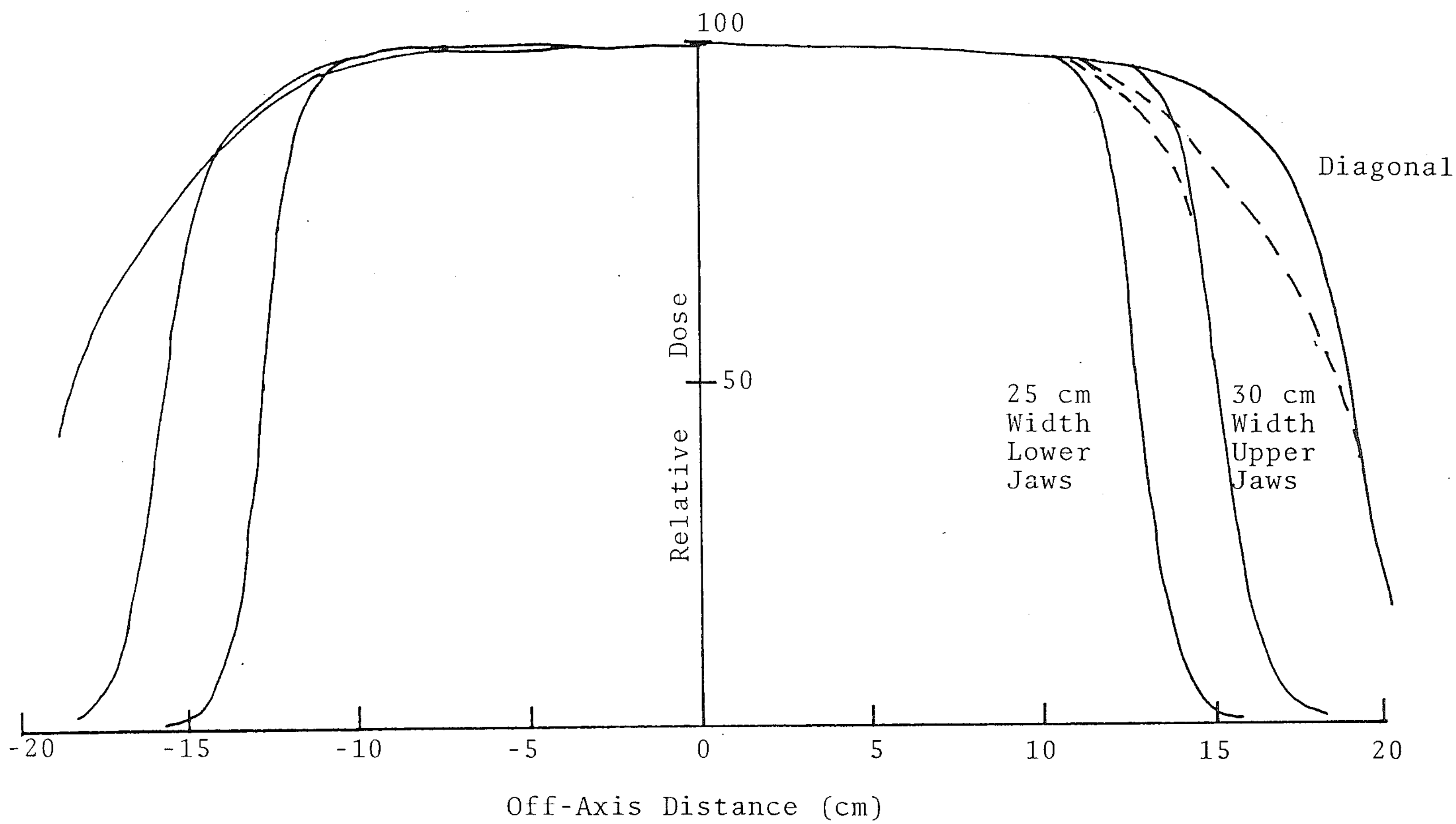

Figure 9

MEVATRON 77 NEW VARIABLE ELECTRON COLLIMATOR

OFF-AXIS RATIOS 12 MeV

100 cm SSD, 25 x 30 cm^2, depth = 3.0 cm

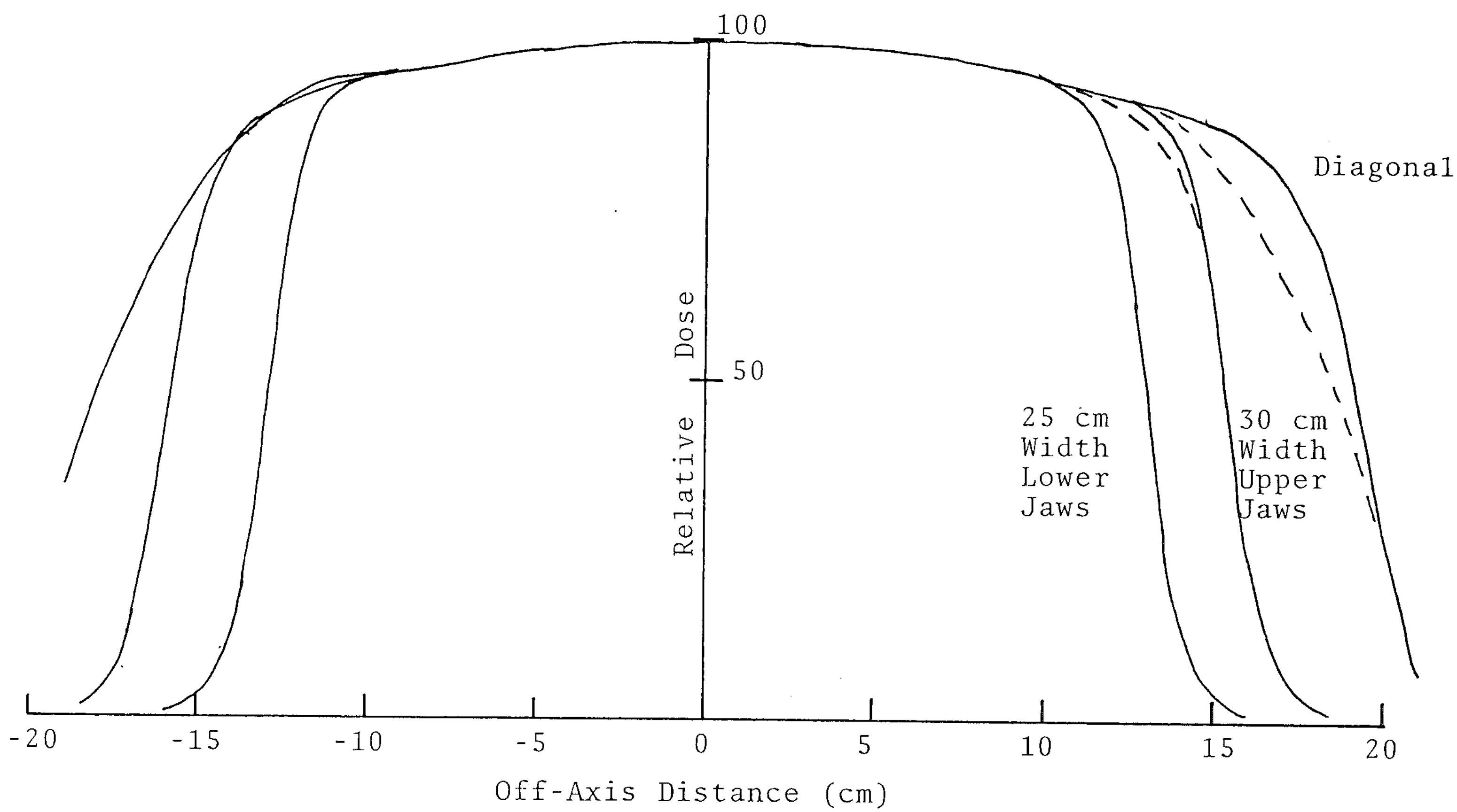

Figure 10

MEVATRON 77 NEW VARIABLE ELECTRON COLLIMATOR

OFF-AXIS RATIOS 18 MeV

100 cm SSD, 25 x 30 cm^2, depth = 4.0 cm

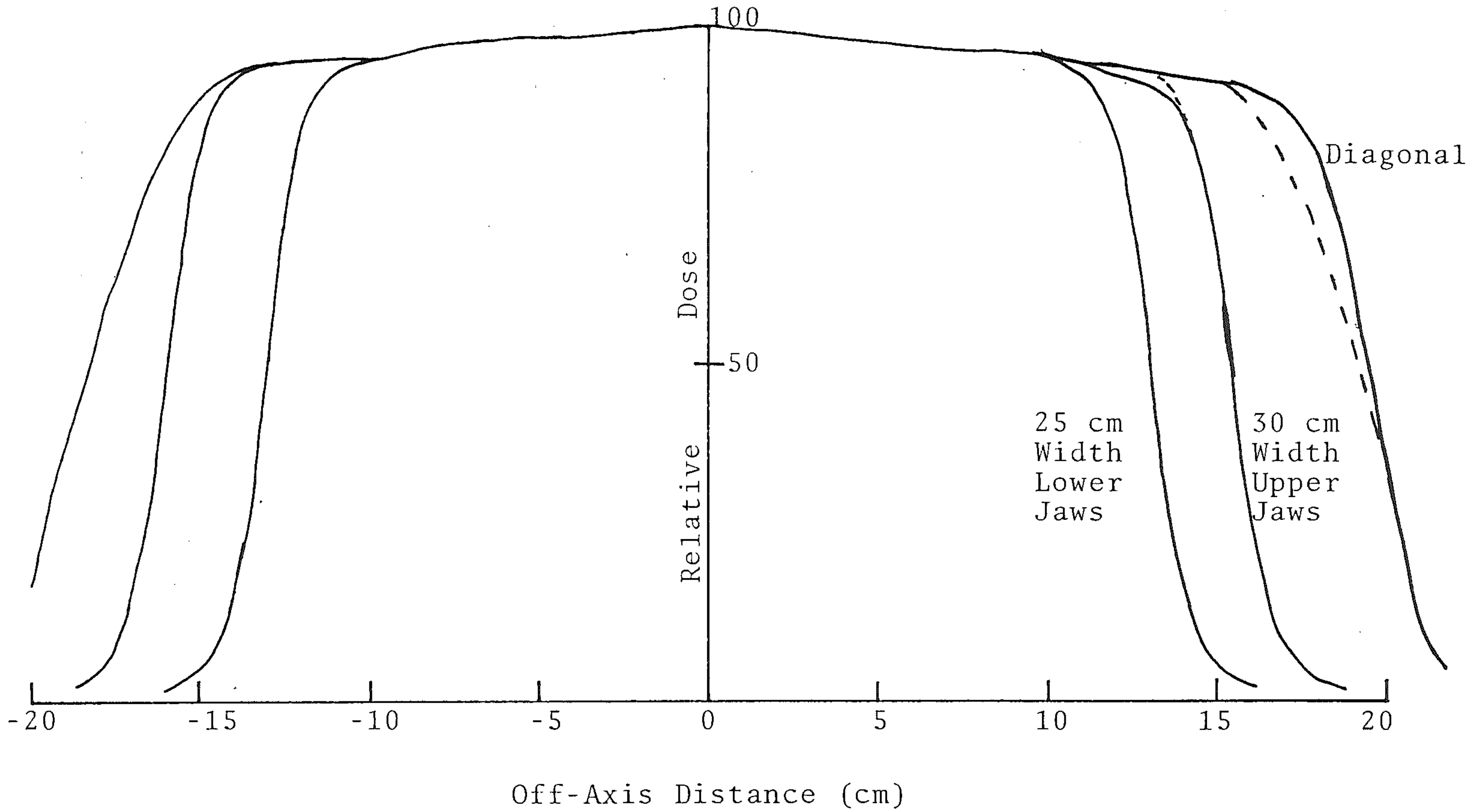

Figure 11

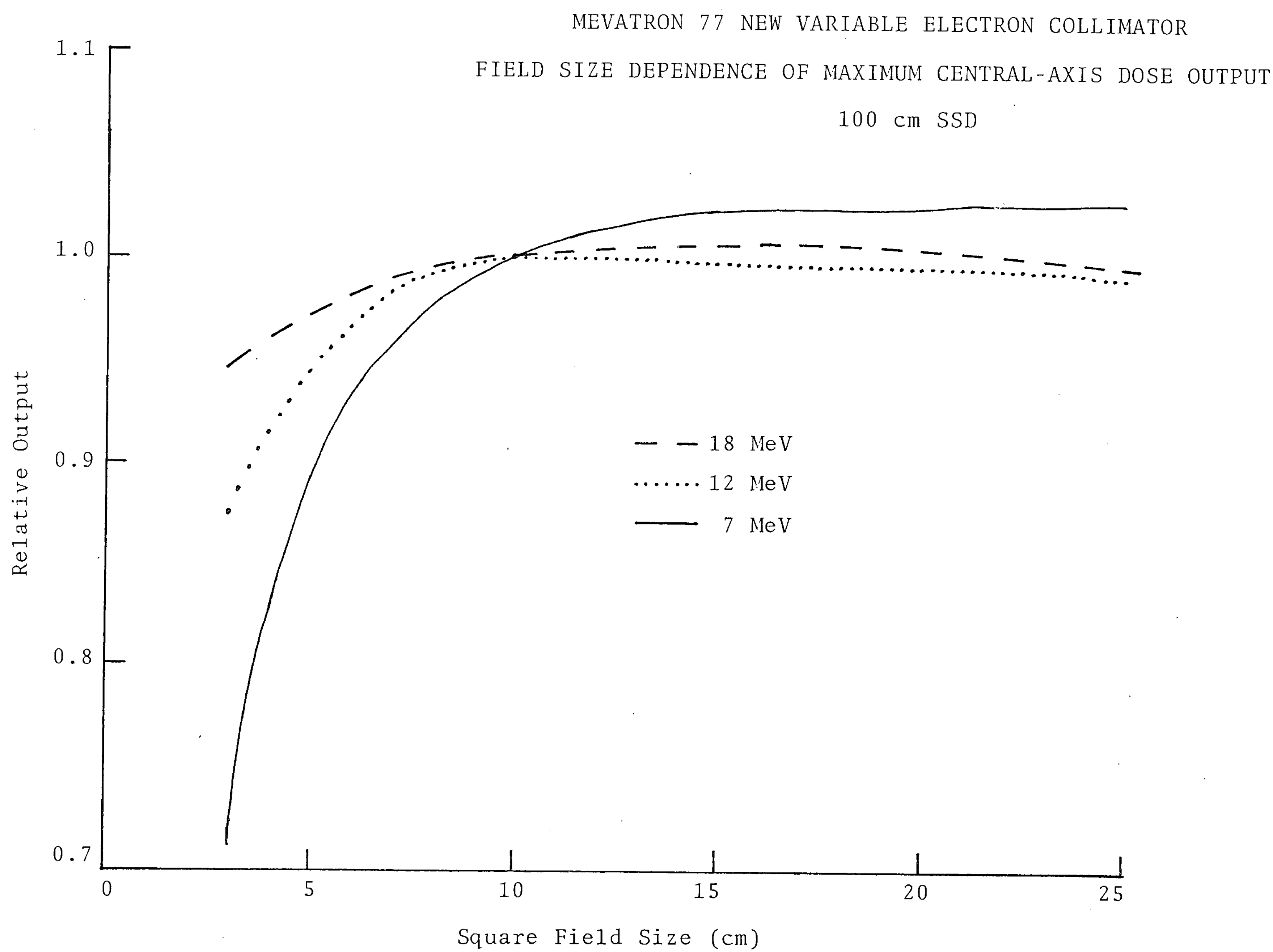
MEVATRON 77 NEW VARIABLE ELECTRON COLLIMATOR
FIELD SIZE DEPENDENCE OF MAXIMUM CENTRAL-AXIS DOSE OUTPUT
100 cm SSD
18 MeV
12 MeV
7 MeV
Relative Output
1.1
1.0
0.9
0.8
0.7
0
5
10
15
20
25
Square Field Size (cm)

Figure 12