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CHARACTERIZATION of a p(66)be(49) NEUTRON THERAPY BEAM II. Skin-Sparing and Dose Transition Effects

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ABSTRACT

Results of build up measurements in A-150 tissue equivalent plastic are presented for a p(66)Be(49) neutron beam. These measurements were taken in air and behind various materials to answer questions about skin sparing, bolussing materials, recovery of skin sparing, and dosimetry in small radiobiological samples. The depth for D_{max} for this beam is 1.6 g cm^{-2}. An algorithm is also presented that reproduces the measured dose build-up curves.

Key Words: p(66)Be(49), neutrons, skin-sparing, build-up, dose transition, bolussing, algorithm.

INTRODUCTION

The results of dose build-up measurements in A-150 TE plastic[1] for a p(66)Be(49) neutron beam are presented here for various field sizes. In addition, the effect of placing different materials immediately upstream of the phantom surface have been investigated. These studies were made to obtain knowledge about the skin-sparing properties of this beam and about the effects of materials proposed for either patient bolussing or for constructing holders used in radiation biology experiments.

EXPERIMENTAL SET-UP

The measurements were made using an A-150 TE-plastic parallel plate extrapolation chamber and A-150 discs of different thicknesses all made by EG&G.[2] This chamber was mounted in a build-up phantom also made of TE-plastic. The phantom consisted of a parallelepiped 20.7 cm high × 21.8 cm wide (perpendicular to the neutron beam) × 16.0 cm long. The phantom had a hole normal to and through the center of the 20.7 × 21.8 cm^2 surface. The hole diameter was just large enough to permit a snug fit for the extrapolation ion chamber and the A-150 absorber discs. Additional hardware outside the phantom maintained the stem of the ionization chamber coaxial with the hole. For all measurements, the entrance face of the phantom was at 153.2 cm from the center of the

Be-target and 28 cm from the collimator exit. The 93 cm long collimators were made of polyethylene concrete.[3]

The extrapolation chamber was operated with a plate spacing of 2.3 mm, at a polarizing voltage of +600 V. Measurements with the extrapolation chamber at both +600 V and -600 V showed that a correction factor of about 0.99 should be applied to the positive voltage collected charge using the thinnest window (2.9 mg cm^{-2}). This correction increases to almost unity at maximum build-up thickness and beyond. The charge from the ionization chamber was collected using essentially the same electronics used for daily beam calibration and dose delivery, which are under continuous computer control.[3,4,5]

Various samples were mounted on a 1.6 mm thick aluminum wheel which could be rotated remotely. This wheel had seven holes 11.5 cm in diameter which could be placed in turn in front of, and concentrically with, the ionization chamber. The downstream faces of the samples were about 3 mm away from the upstream face of the phantom. Up to six samples were mounted on this disc. The "in air" build-up measurements were taken using the empty hole, except for the 30×30 cm^2 beam which was measured without the disc.

Two types of dose transition measurements were made. Paraffin, low melting point (LMP) wax[6] and polyethylene were studied for clinical applications as possible bolus materials. Measurements behind teflon, lucite and polystyrene

were mainly made to answer questions about dosimetry inside fixtures designed for radiobiology experiments.

RESULTS

Figure 1 shows the dose build-up in A-150 TE-plastic for 6×6 cm^2, 15x15 cm^2 and 30x30 cm^2 field sizes (defined at the surface of the phantom). The three curves have been normalized to unity at a depth of 1.6 g cm^{-2}. The solid lines are the fits to the data using an algorithm discussed below.

Figure 2 shows the dose transition in TE-plastic behind various bolus-like materials:

(a) 0.54 g cm^{-2} of paraffin with a 15×15 cm^2 field.

(b) 0.52 g cm^{-2} of low-metling-point wax[6] with a 15×15 cm^2 field, and

(c) 0.60 g cm^{-2} of polyethylene with a 6×6 cm^2 field.

The solid curve represents the build-up for the 15×15 cm^2 field as shown in Fig. 1. All the measurements have been normalized to the build-up maximum dose at 1.6 g cm^{-2} from the corresponding field size, as measured above with the empty hole. The curves have been displaced so that the abscissa respresents total absorber thickness (sample plus TE-plastic) in g cm^{-2}.

Figure 3 shows the dose transition in TE-plastic for a 6×6 cm^2 beam, behind:

(a) 0.73 g cm^{-2} and,

(b) 2.25 g cm^{-2} of polymethyl-methacrylate (lucite or perspex) as well as,

(c) 0.69 g cm^{-2} and

(d) 2.04 g cm^{-2} of polystyrene and

(e) 1.44 g cm^{-2} of teflon (PTFE).

The curves have been normalized to the "empty hole" dose at a depth 1.6 g cm^{-2}, as in Fig. 2.

Figure 4 shows how a thin lead foil causes substantial skin sparing recovery when placed on the downstream face of LMP wax.[7,8] The two curves are for a 15×15 cm^2 beam. Curve (a) shows the dose transition in TE-plastic behind 1.0 g cm^{-2} of LMP wax. Curve (b) was obtained by placing a 0.13 mm lead foil between the LMP wax and the phantom.

The curves are normalized to unity at a depth of 0.8 g cm^{-2} of TE-plastic, the position of maximum dose in curve (b).

DISCUSSION AND CONCLUSIONS

The build-up curves of Fig. 1 have a definite field size dependence, mostly in the value of the entrance dose, from about 40% for the 6×6 cm^2 to about 50% for the 15×15 cm^2 and almost 60% for the 30×30 cm^2 field size. The depth at which

90% of maximum dose is reached, on the other hand, varies little for the three field sizes, from 0.4 g cm^{-2} at 6×6 cm^2 to 0.3 g cm^{-2} at 30×30 cm^2. No difference can be noticed in the position of the flat maximum at about 1.6 g cm^{-2}. Although these build-up curves were measured using a different geometry than the depth dose curves presented in Paper I,[4] their behaviour cannot be too different in the new system geometry, with the possible exception of the values of entrance dose, which could be influenced most by scatter from the internal faces of the collimator. The algorithm used to describe the depth doses (Eq. 1 in Paper I), was therefore applied to these measurements:

$$CADD(ESQ,SSD,z) = U1 \cdot [BUF(z)] \cdot e^{-\frac{z}{U2}} \cdot \left(\frac{190}{SSD+z}\right)^2, \qquad (1)$$

where :SSD is the source to skin distance (cm),

z is the depth in cm of TE-solution
U1 is a normalizing factor, and

$$BUF(z) = 1 - U3 \cdot e^{-(z/U4)^{U5}} \qquad (2)$$

is the build-up factor. Parameters U2 through U5 are functions of ESQ, the equivalent square at the surface, as shown in Paper I.[4] The above algorithm, with the values given in Paper I, reproduces the measured build-up curves

adequately within 0.3 g cm^{-2} deviation, but predicts a faster rise to the 90% dose level than observed. A modified build-up factor was therefore developed and fitted to the present data using a least-square minimization program:[4]

$$BUF(z) = 1-[U3 + U6\cdot(z/U4) + U7\cdot(z/U4)^2]\,e^{-(z/U4)^{U5}} \qquad (3)$$

where

$$\begin{aligned} U3 &= 0.793 \\ U4 &= 0.191 + 0.122 \cdot ESQ \\ U5 &= 0.467 \\ U6 &= 0.0307 \cdot ESQ - 0.0546 \\ U7 &= 0.0159 + 0.0089 \cdot ESQ - 0.0058 \cdot ESQ^2. \end{aligned} \qquad (4)$$

This final formulation was used to draw the solid curves in Fig. 1.

The dose transition curves in Fig. 2 show that the use of hydrogenous bolus material on the skin for superficial ulcerating lesions or suspect surgical scars would overdose the skin surface relative to the prescribed D_{max} dose by 3% to 8%, depending on the material. For simple bolus application and most uniform dose, it seems that a 6 mm layer of folded polyethylene sheet is a satisfactory solution. This method has been used at Fermilab when high skin dose was indicated. If tissue compensation is required to improve overall dose distribution, then LMP wax has definite handling

advantages and its transition effect is clinically acceptable. The LMP wax may be improved as a bolus material by mixing in powdered teflon. For instances where tissue compensation is required without the need to bring the skin to full dose, the use of a thin lead foil recovers part of the skin sparing of the open beam. It can be seen from Fig. 4 that a 30% reduction in the skin entrance dose can be achieved with just 1/8 mm of lead. This effect is in good agreement with the results of Smathers et al.[8] If more skin sparing is required, four such layers will probably reduce the entrance dose to close to the open beam value.[8]

The structural materials shown in Fig. 3 have dose transition effects in the first few millimeters that depend on the thickness as well as the material used. These effects introduce dose uncertainties in the often small biological samples used in experimental irradiation. Therefore, it has been the practice at Fermilab to construct of A-150 TE-plastic all parts of holders for radiation biology experiments which will be in the neutron beam.

The behaviour of these dose transition curves may be understood semi-quantitatively. The lucite and polystyrene samples have less relative hydrogen mass (approx. 7.6%) than A-150 (10.2%).[9] As hydrogen accounts for about 60% of the total kerma,[10] there is a discontinuity in the kerma at the interface of about 15%. In the case of the thick samples (2.0-2.2 g cm^{-2}), transient charged particle equilibrium has

already been reached within the samples, and the dose defect at the interface should be about 15% of the eventual maximum, as observed. This dose transition is accomplished in a relatively short depth. In the case of the thin samples (about 0.7 g cm^{-2}) the charged particle flux had not yet reached transient equilibrium at the interface. Thus, a lower relative transition dose at the interface is expected and an additional thickness of A-150 is needed to reach transient charged particle equilibrium and compensate for the change in kerma. The dose maxima in A-150 are thus reached in both cases at larger total thicknesses, in g cm^{-2}, than that observed for the "in air" build-up. The additional masses per unit area are approximately 1.0 and 0.2 g cm^{-2}, respectively, for the thick and thin samples. As the kerma for this beam attenuates in tissue at an approximate rate of 5% per cm,[4] one should expect dose maxima of approximately 95% and 99% of the "in air" dose maximum, respectively. This agrees well with the measurements.

The transition curve behind • teflon has completely different characteristics. As teflon contains no hydrogen, this transition resembles the "in air" dose build-up curve.

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FIGURE CAPTIONS

Fig. 1 Dose build-up in A-150 TE-plastic for 6×6 cm^2, 15×15 cm^2 and 30×30 cm^2 field sizes. The curves are normalized to unity at 1.6 g cm^{-2}. Solid lines are fits using an algorithm discussed in the text.

Fig. 2 Dose transition in A-150 behind:

△ 0.54 g cm^{-2} of paraffin (using the 15×15 cm^2 field)

□ 0.52 g cm^{-2} of low-melting point wax (using the 15×15cm^2 field)

◎ 0.60 g cm^{-2} of polyethele (using the 6×6 cm^2 field)

The solid curve represents the "in air" build-up for the 15×15 cm^2 field size. All data normalized to "in air" dose at 1.6 g cm^{-2} for corresponding collimator. Abscissa represents total thickness of sample plus A-150 in g cm^{-2}.

Fig. 3 Dose transition in A-150 using a 6×6 cm^2 field size behind:

○ 0.67 g cm^{-2} polystyrene,

● 2.04 g cm^{-2} polystyrene,

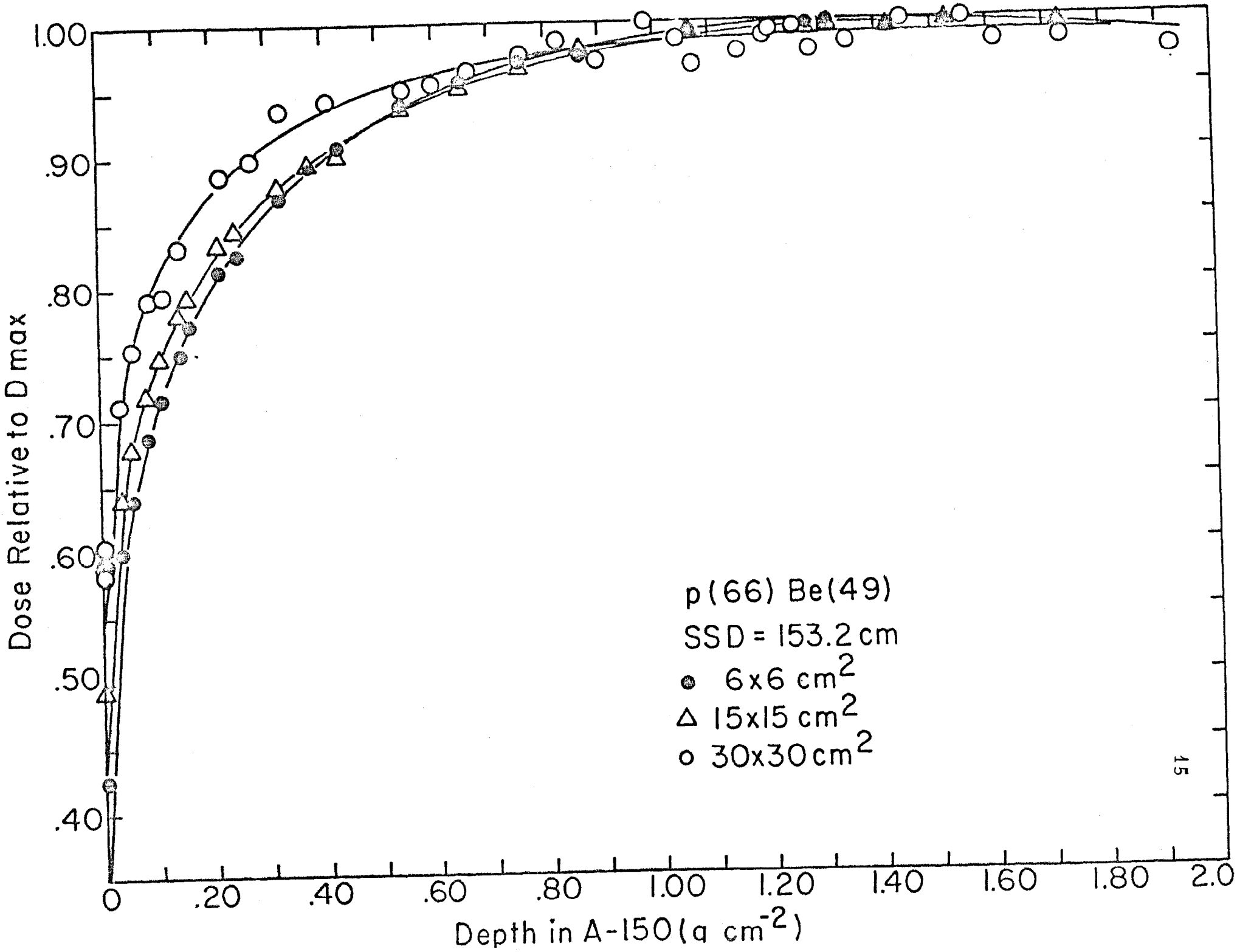
△ 0.73 g cm^{-2} lucite,

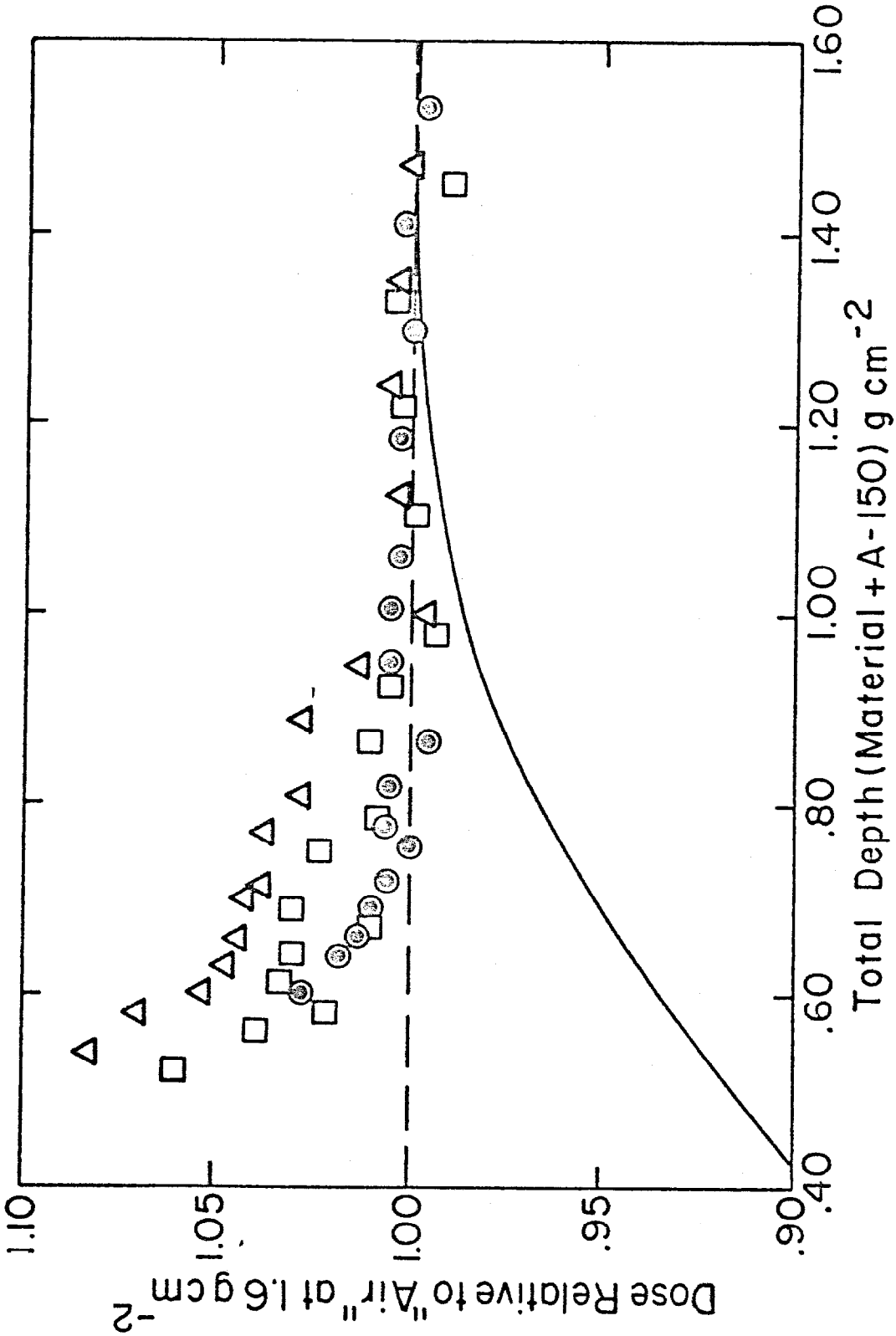
▼ 2.25 g cm^{-2} lucite,

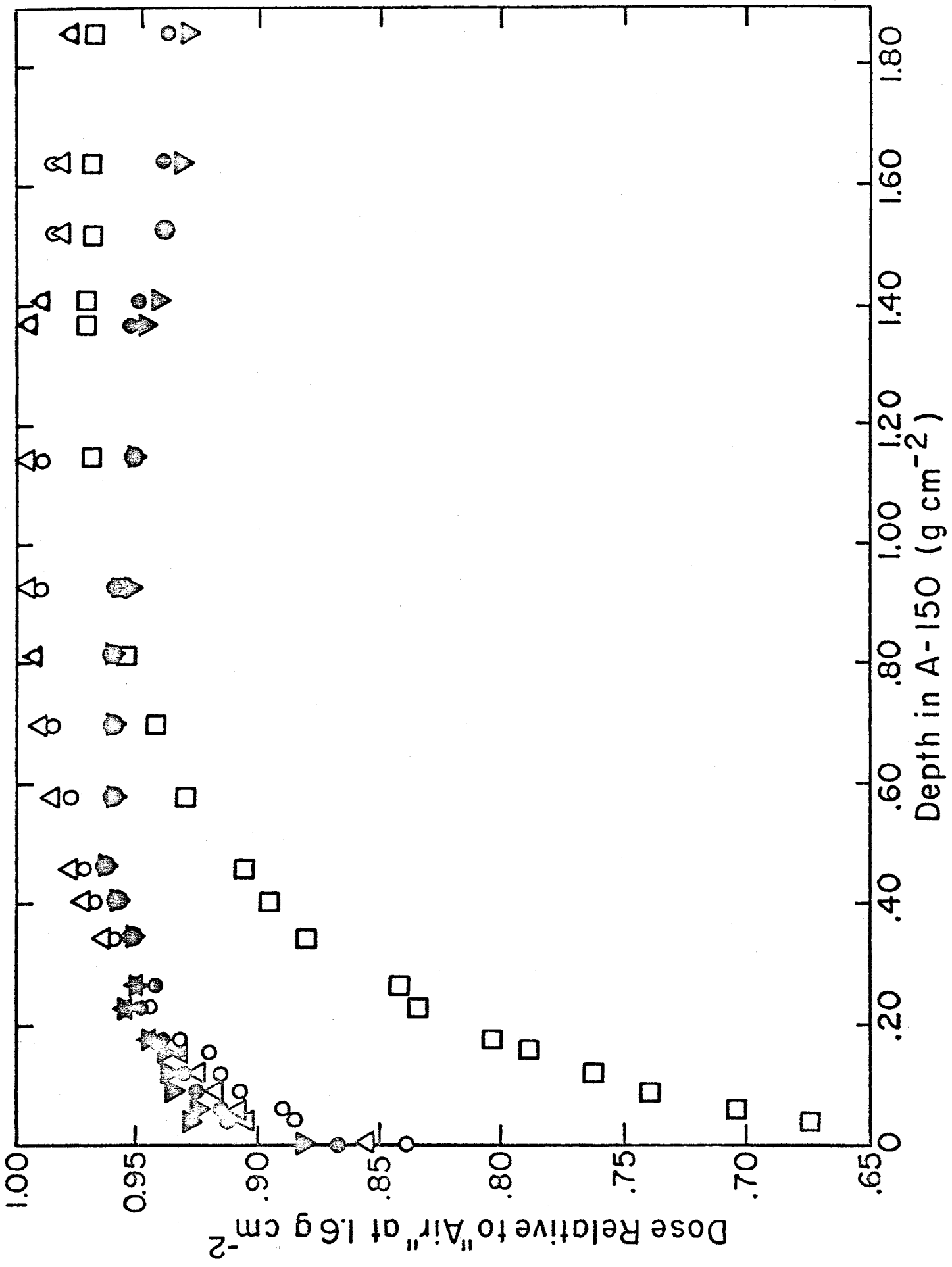
□ 1.44 g cm^{-2} teflon.

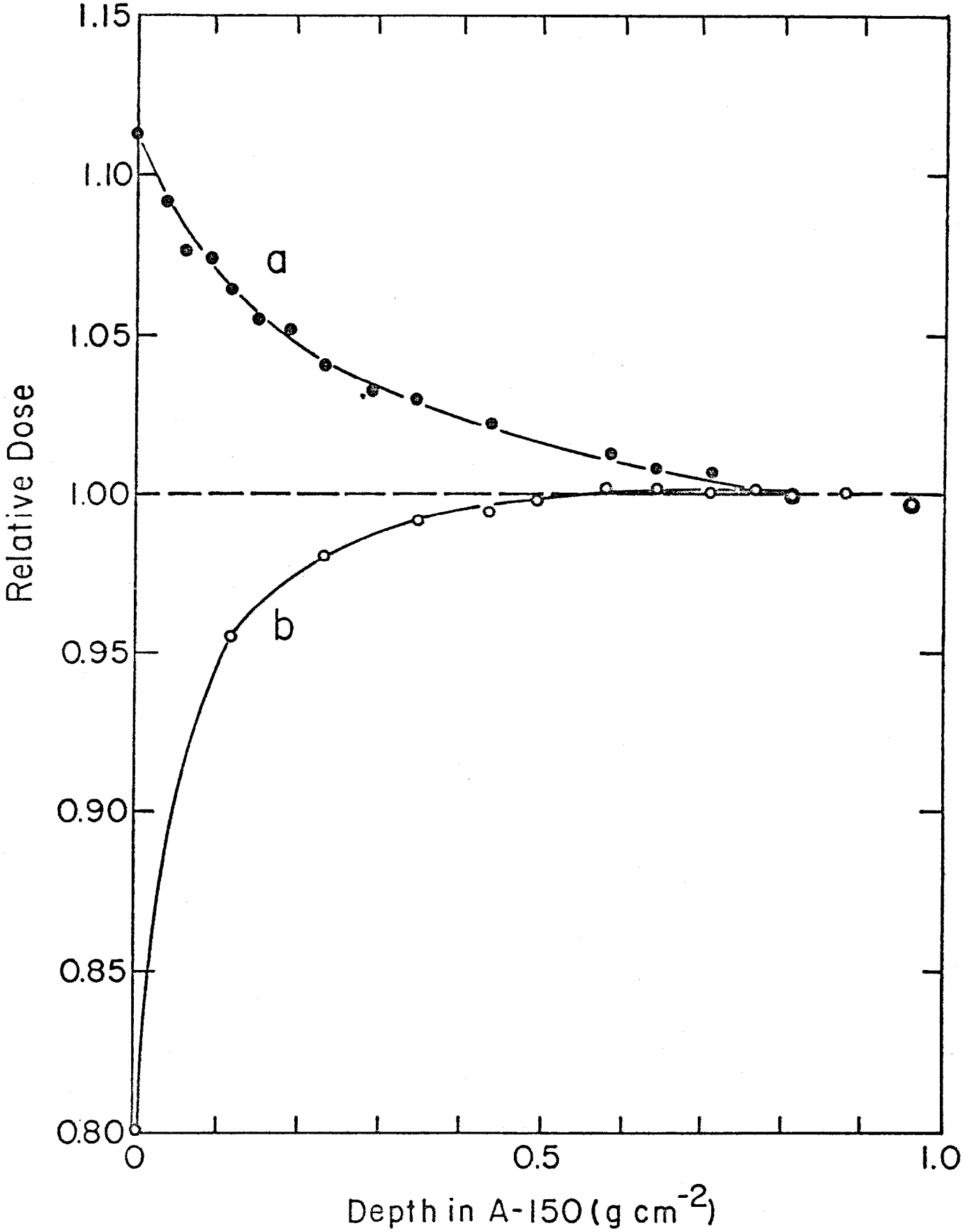
All data normalized to the "in air" dose at 1.6 g cm^{-2} for the 6 × 6 cm^2 field size. Abscissa represents thickness of A-150 only. Normalized entrance dose behind teflon (not shown) was 0.55.

Fig. 4 Curve (a) represents dose transition in A-150 behind 1.0 g cm^{-2} of low-melting-point wax. Curve (b) represents the transition when 0.13 mm Pb foil is placed between wax and build-up phantom. Curves normalized to unity at depth of 0.8 g cm^{-2}. Abscissa represents thickness of A-150 only.


1.00
.90
.80
.70
.60
.50
.40
Dose Relative to Dmax
0
.20
.40
.60
.80
1.00
1.20
1.40
1.60
1.80
2.0
Depth in A-150 (g cm^{-2})
p(66) Be(49)
SSD = 153.2 cm
6x6 cm^2
15x15 cm^2
30x30 cm^2


Dose Relative to "Air" at 1.6 g cm^{-2}
1.10
1.05
1.00
.95
.90
.40
.60
.80
1.00
1.20
1.40
1.60
Total Depth (Material + A-150) g cm^{-2}


Dose Relative to "Air" at 1.6 g cm^{-2}
1.00
0.95
.90
.85
.80
.75
.70
.65
0
.20
.40
.60
.80
1.00
1.20
1.40
1.60
1.80
Depth in A-150 (g cm^{-2})


1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
Relative Dose
a
b
0
0.5
1.0
Depth in A-150 (g cm^{-2})