Shielding of First Optics Enclosure against Secondary Gas Bremsstrahlung *

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Abstract

The shielding calculations using the Monte Carlo simulations against the secondary gas bremsstrahlung are performed for the First Optics Enclosure (FOE). Various sizes of copper metals are used as a source of the secondary gas bremsstrahlung. Two methods, the direct approach and the two-step approach, are used to evaluate the energy deposition in the water phantom which is placed outside the walls of the FOE. The average dose behind the back and side walls are studied in detail.

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I. INTRODUCTION

Interactions of high energy electrons with residual molecules in the vacuum chamber produce the gas bremsstrahlung, the maximum energy 2.9 GeV assumed. The highly forward peaked radiation propagates in the beamline with the synchrotron radiation to the First Optics Enclosure (FOE). The possible targets in the FOE that the gas bremsstrahlung strikes are slits, filters, mirrors, monochromators and beam stops. The scattering from these components is referred to as secondary gas bremsstrahlung [1], [2].

For the safe operation of the synchrotron facility, a beam shutter/stop made from tungsten is placed in the beam line along with other components mentioned above. The walls (back and side) and roof of the FOE are constructed from lead. Our aim is to develop a unified method in which the shielding design of the FOE against secondary bremsstrahlung is achieved by applying the EGS4 code [3] to the entire FOE.

It is not practical to estimate the radiation due to secondary gas bremsstrahlung from each component. Instead a thin copper metal is chosen as a representative source of secondary gas bremsstrahlung. The copper metal is placed at the entrance to the FOE, which sets the origin of the coordinate system. Fig.1 shows the coordinate system and the dimensions of the FOE used in the calculation.

To assess the radiation dose outside the FOE, a water phantom is employed in which the energy deposition is estimated by EGS4. We calculate the energy deposition in two ways [4], the two-step approach and and the direct approach. Section II gives the geometry used in the EGS4 model calculations. Section III deals with the two-step approach and Section IV presents the results from the direct approach. The conclusion is given in Section V.

II. GEOMETRY

As shown in Fig.1, the FOE is assumed to be

- FOE dimensions = 190 cm * 340 cm * 600 cm
- Beam height from floor = 140 cm
- Beam entrance point from side = 95 cm

The dimensions of tungsten stop and the copper metal are denoted by (A, B, C) in cm, for example, W(10, 10, 10) is the tungsten stop of size 10 cm x 10 cm x 10 cm. In all of EGS4 simulations, the tungsten stop, W(10, 10, 10), is palced at 500 cm in Z dierction and the dimension of copper Cu(A, B, C), which is set at the origin, is varied. The length is in cm unless otherwise specified.

The lead wall thickness of the FOE is assumed;

- Back wall = 8 cm , reinforced by a Pb(100, 100, 5) centre piece.
- Side wall = 3 cm

III. AVERAGE DOSE EVALUATION USING TWO-STEP APPROACH

The copper metal is bombarded by the gas bremsstrahlung, thereby producing the secondary gas bremsstrahlung in the FOE. The secondary gas bremsstrahlung then interacts with the tungsten beam stop, lead centre piece and finally the lead back wall. Immediately behind the lead back wall a 30 cm long cylindrical water phantom of radius up to 100 cm is placed. See Fig.2 for a schematic sketch of a cylindrical water phantom.

The two-step approach consists of first obtaining the energy, the (X,Y) coordinates and directional cosines of photons at Z=600 cm. Using this information as the input data the energy deposition in the cylindrical water phantom is then calculated.

The average dose as a function of radius in the water phantom at 2.5 cm depth (between 2 and 3 cm) is shown in Fig.3 for the several copper thicknesses. From this figure the copper scatterer of 5 cm thick is shown to act as a modulator as far as the average dose at the back is concerned. Also it is found that the average dose within the radius about 11 cm becomes the maximum with Cu=(4,4,3). In Fig.4 the average dose as a function of depth in water phantom is shown for several radii with Cu=(4,4,3). To see how the average dose varies with the distance from the beam axis, the average dose between the radius R and $R+1$ cm is investigated. At the fixed depths of 2.5 cm (between 2 and 3 cm) and 8.5 cm (between 8 cm and 9 cm) the average dose distributions between the adjacent radii are obtained and the results are shown in Fig.5 for a Cu=(4, 4, 3) scatterer.

The two-step approach provides the dose distribution in detail both in the longitudinal and the radial direction. However this method gives the dose at the back only. We present in the next Section IV the direct approach by which the absorbed dose at the back, sides and roof are calculated simultaneously.

IV. ABSORBED DOSE EVALUATION USING DIRECT APPROACH

In the direct approach the FOE is encompassed by a layer of water 2 cm thick [4] and the energy depositions are calculated in some chosen volumes of the water phantom. In this report the longitudinal dimensions of the water phantom is extended to 14 cm, allowing a better comparison of the direct approach with the two-step approach.

We examine the radiation through the back wall, which consists of 8 cm of lead plus a lead centre piece Pb(100,100,5) around the beam axis. The scoring area is taken 10 cm by 10 cm around the beam axis. This area corresponds to the surface area of the tungsten beam stop. Although the scoring area (5 cm radius) used in the two-step approach does not match exactly with that of the tungsten stop due to the cylindrical water phantom, it is, nonetheless, of interest to compare the average doses of the two methods. The results are shown in Fig.6 and Fig.7 for the copper scatterers Cu(4,4,3) and Cu(4,4,5), respectively.

We now turn our attention to the average dose along the side wall. The side wall is assumed to be constructed by lead 3 cm thick. The length of the side of the FOE is 6 meters and 0.95 meters to the side from the beam axis (See Fig.1). Since the absorbed dose varies with the Z coordinate, the length of the side is divided into 12 sections, each 50 cm long. The scoring area of the side is taken as 4 cm by 50 cm, centred around the beam axis. This area is denoted by "Side". The second scoring area "Side UP" is taken as 3 cm by 50 cm, 3 cm being the difference between the Y coordinates of a tungsten stop and a copper scatterer. See Fig.1b. The third scoring area denoted by "Side UUP" is an area of a 45 cm by 50 cm slot. (The Y coordinate of a lead centre piece is 50 cm.) The energy deposition in the water phantom is obtained when the radiation is attenuated by side wall of lead 3 cm thick. The average doses as a function of the Z coordinate are shown in Fig.8 for a copper scatterer Cu(4,4,3). Fig.9 shows the results for Cu(5,5,5). From these figures it is clear that the highest average dose occurs either in the vicinity of a tungsten beam stop or a copper scatterer. Hence if the potential source is known, the installation of local shielding around the source is recommended to lower the radiation level on the side walls. With regard to the average dose expected on the roof the reader is referred to [4].

The average dose equivalent rate is obtained by multiplying the average dose by the N_γ, the number of photons per unit time. At the Canadian Light Source (CLS) the parameters to obtain N_γ are, for example,

- the electron energy is 2.9 GeV.
- the stored current is 500 mA.
- the gas pressure in the storage ring is 133 nPa (10^{-9} torr).
- the length of straight section is 7.626 m.
- the effective charge Z of the residual gas is 8.1.
- the temperature is taken to be 20°C.

With these parameters, N_γ takes a value 8.1773×10^8 [photons/hr]. Hence the average dose 1.23×10^{-15} Gy/photon yields the average dose equivalent rate roughly 1 μSv/hr.

V. CONCLUSION

The shielding against secondary gas bremsstrahlung is performed for the First Optics Enclosure(FOE). The EGS4 code is applied to the entire FOE. Various thicknesses of copper scatterers are used for the source of secondary gas bremsstrahlung.

In the two-step approach the energy deposition in the cylindrical water phantom, placed behind the back wall is calculated in detail as a function of both depth and radius.

In the direct approach, the FOE is surrounded by a water phantom and the energy depositions in the water phantom behind the back wall, side wall and the roof are obtained simultaneously.

All indications are that the shielding design study of FOE against the secondary gas bremsstrahlung can be carried out by applying the EGS4 code to the entire FOE structure.

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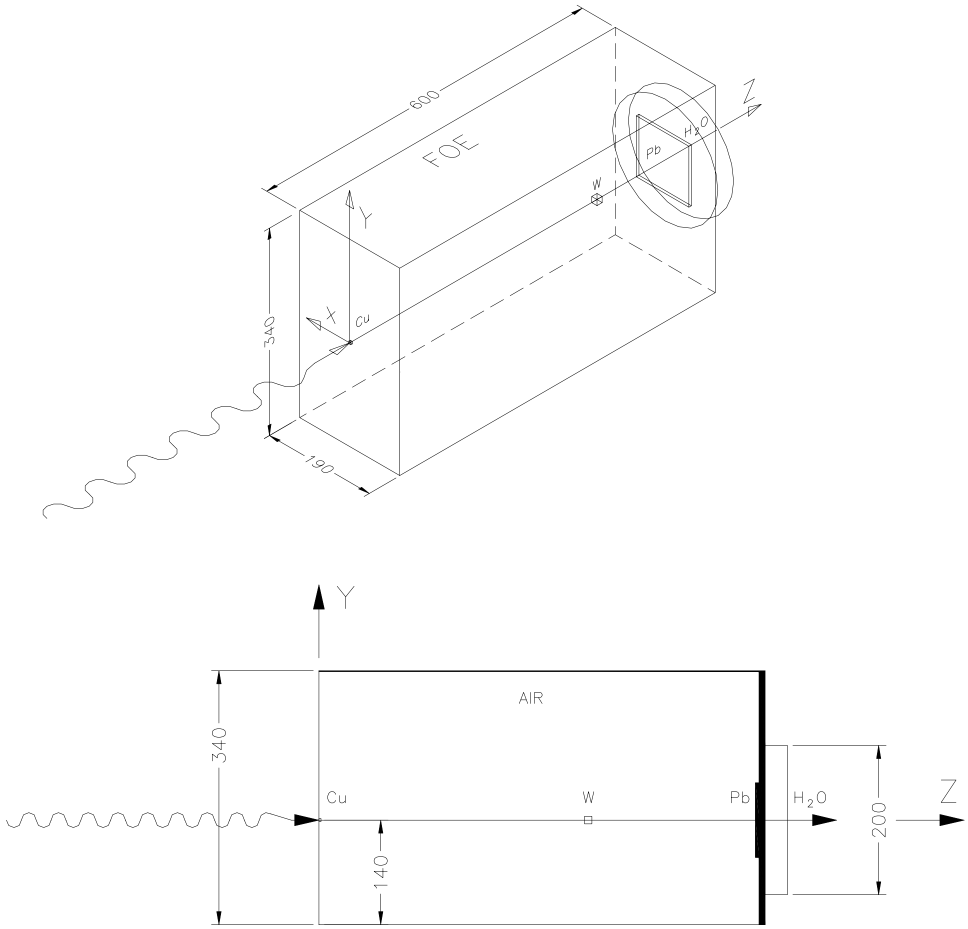

FIG. 1A. Schematic View of FOE and Components
(all dimensions are in cm)

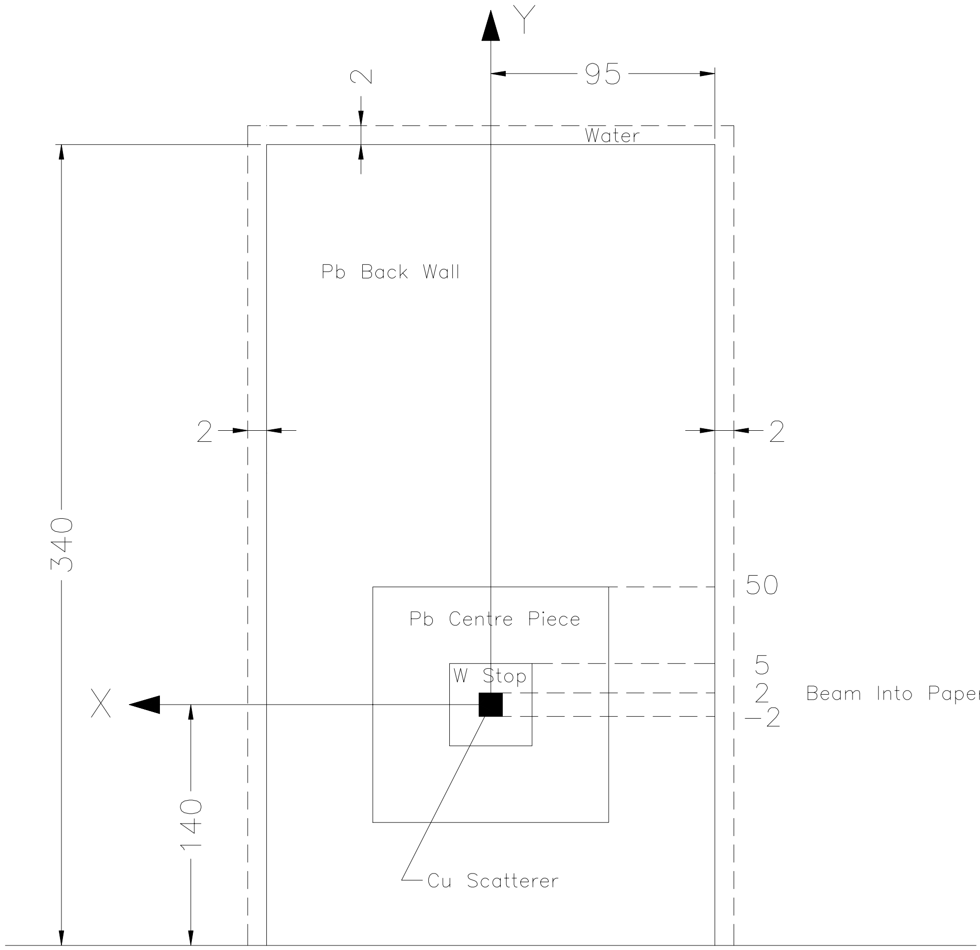

FIG. 1B. Front View of FOE and Component.
(all dimensions are in cm but not in scale)

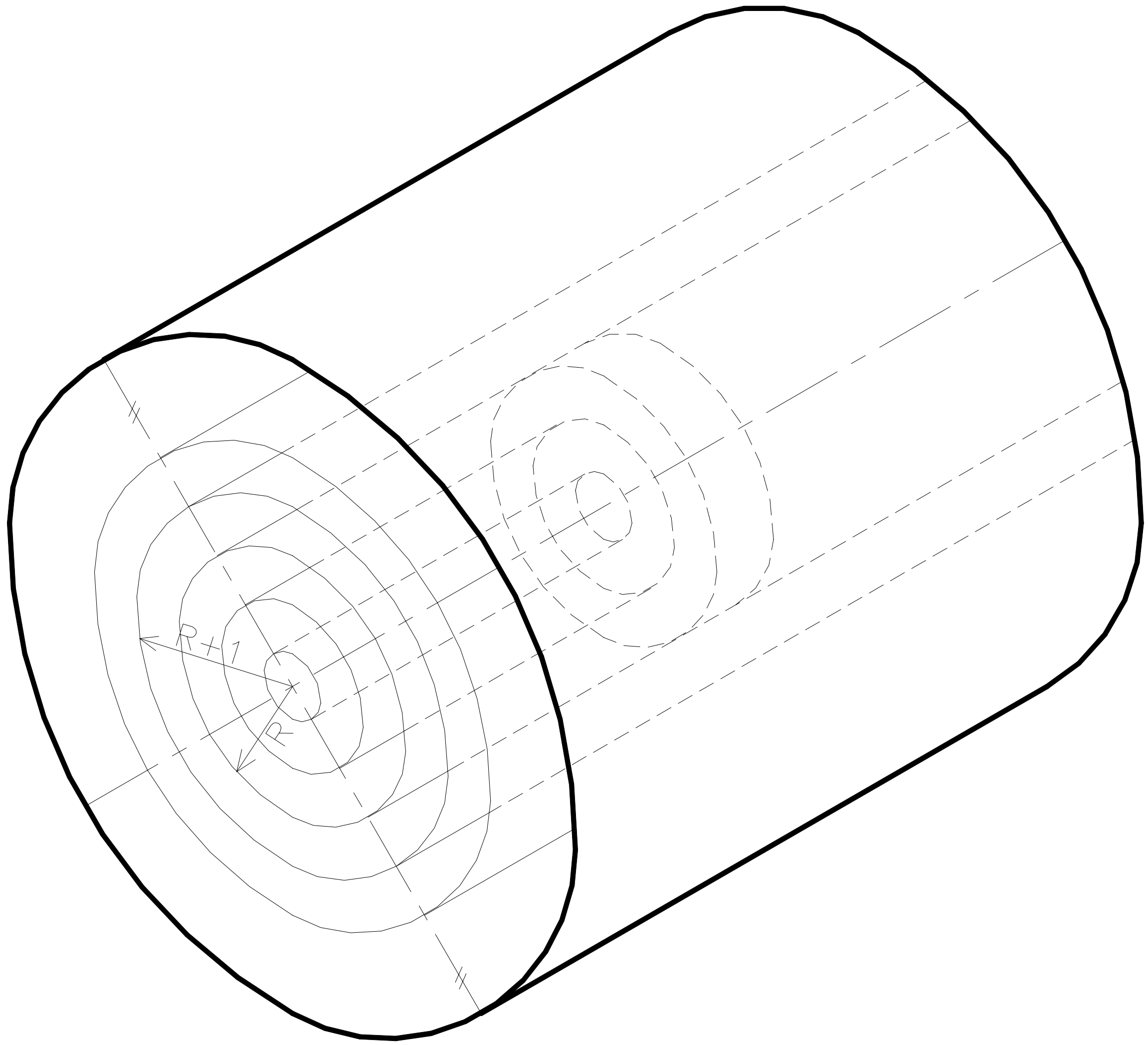

Fig. 2 Schematic View of Cylindrical Water Phantom.

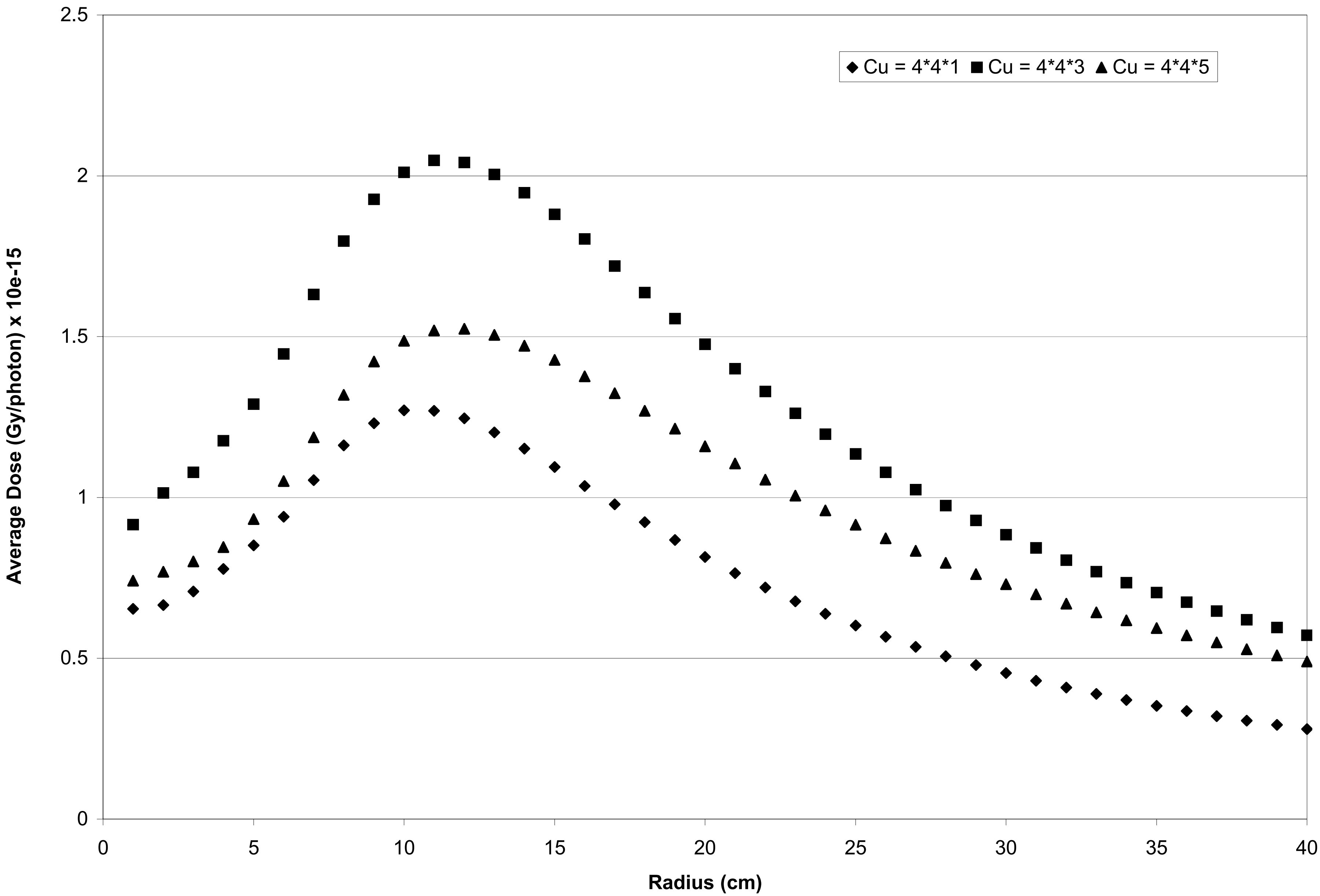

Fig. 3. Average dose as a function of radius in water phantom at 2.5cm depth.

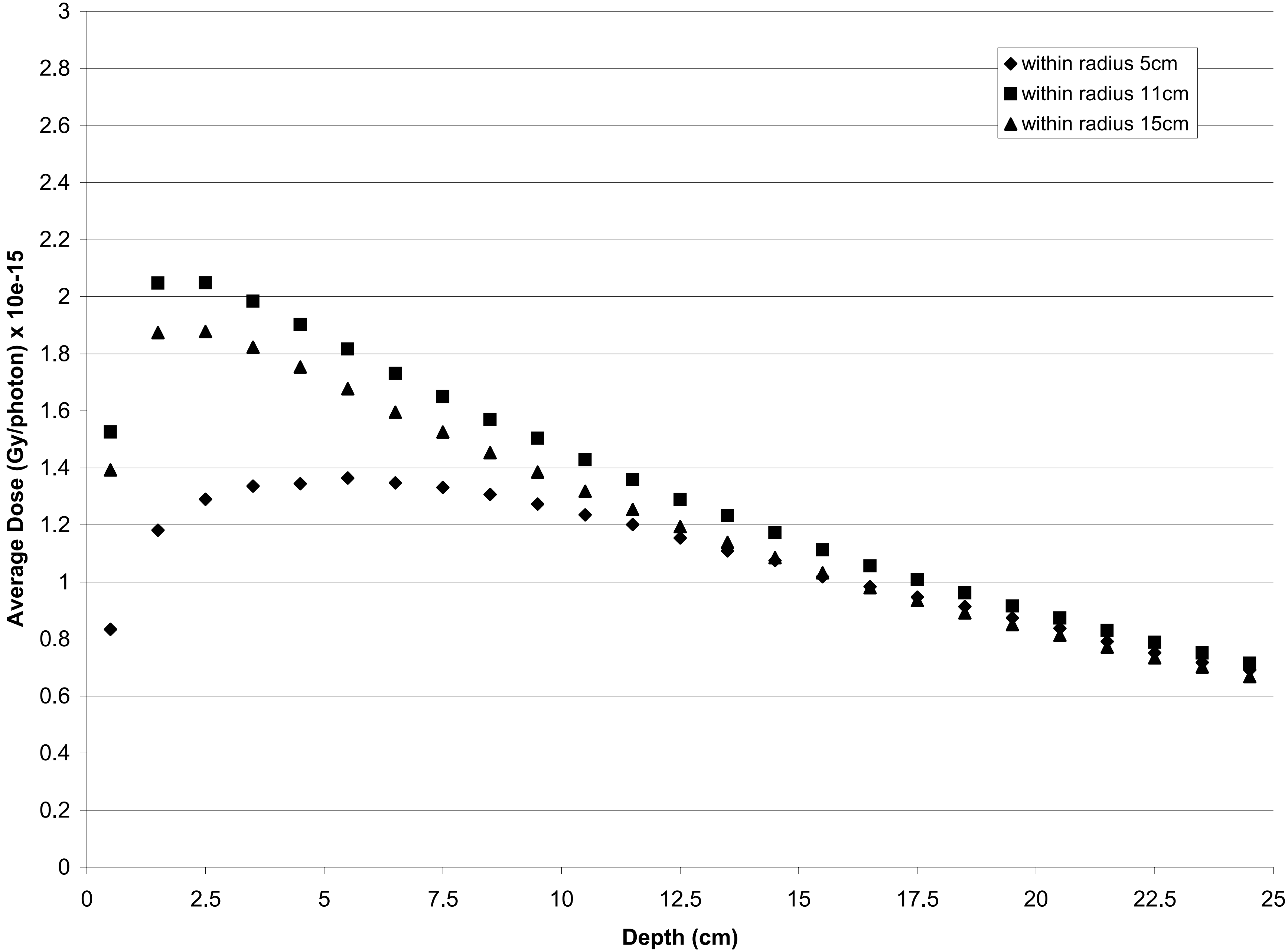

Fig. 4. Average dose as a function of depth in water phantom for Cu = 4*4*3.

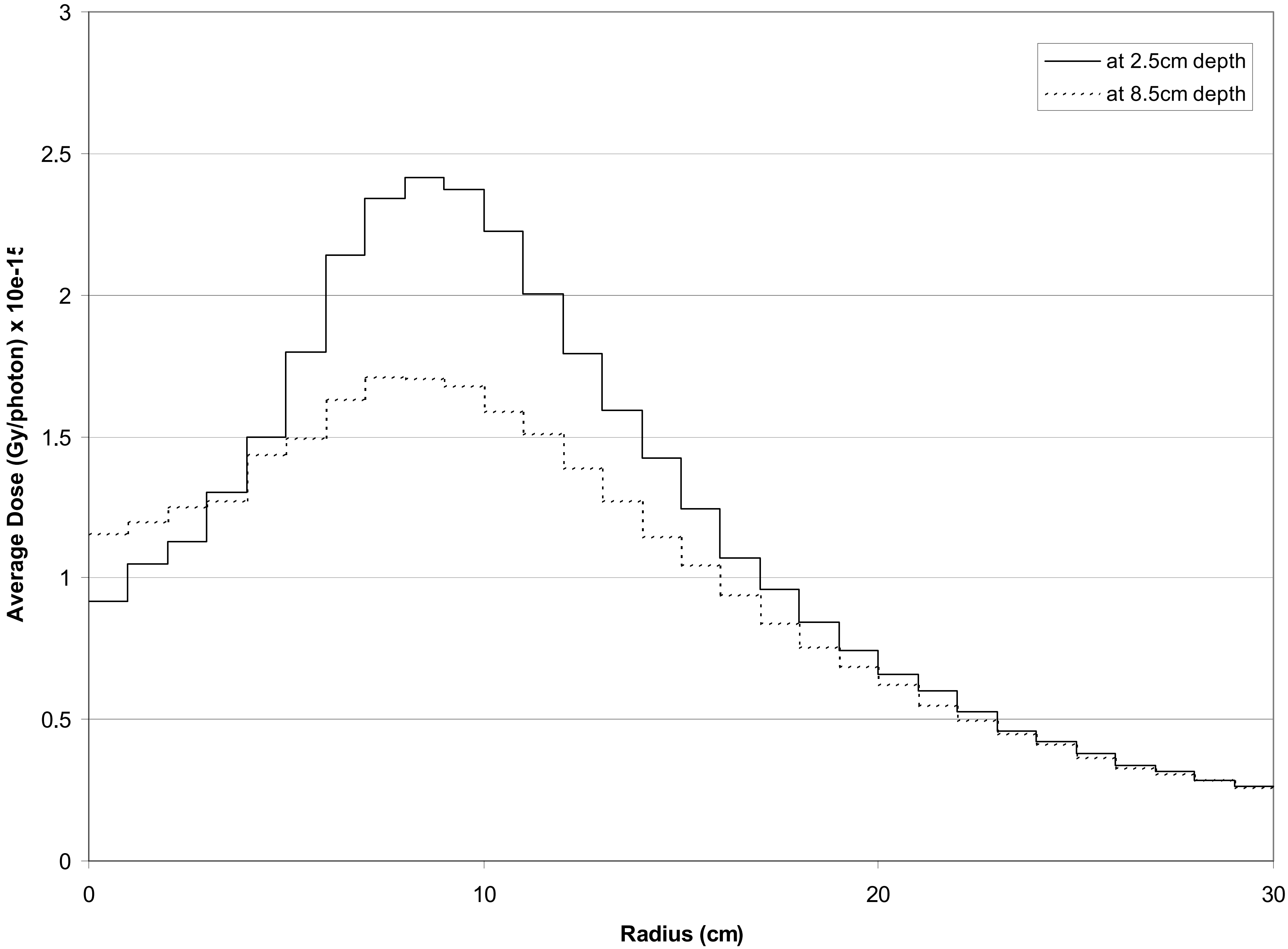

Fig. 5. Average dose between adjacent radii in water phantom for Cu = 4*4*3.

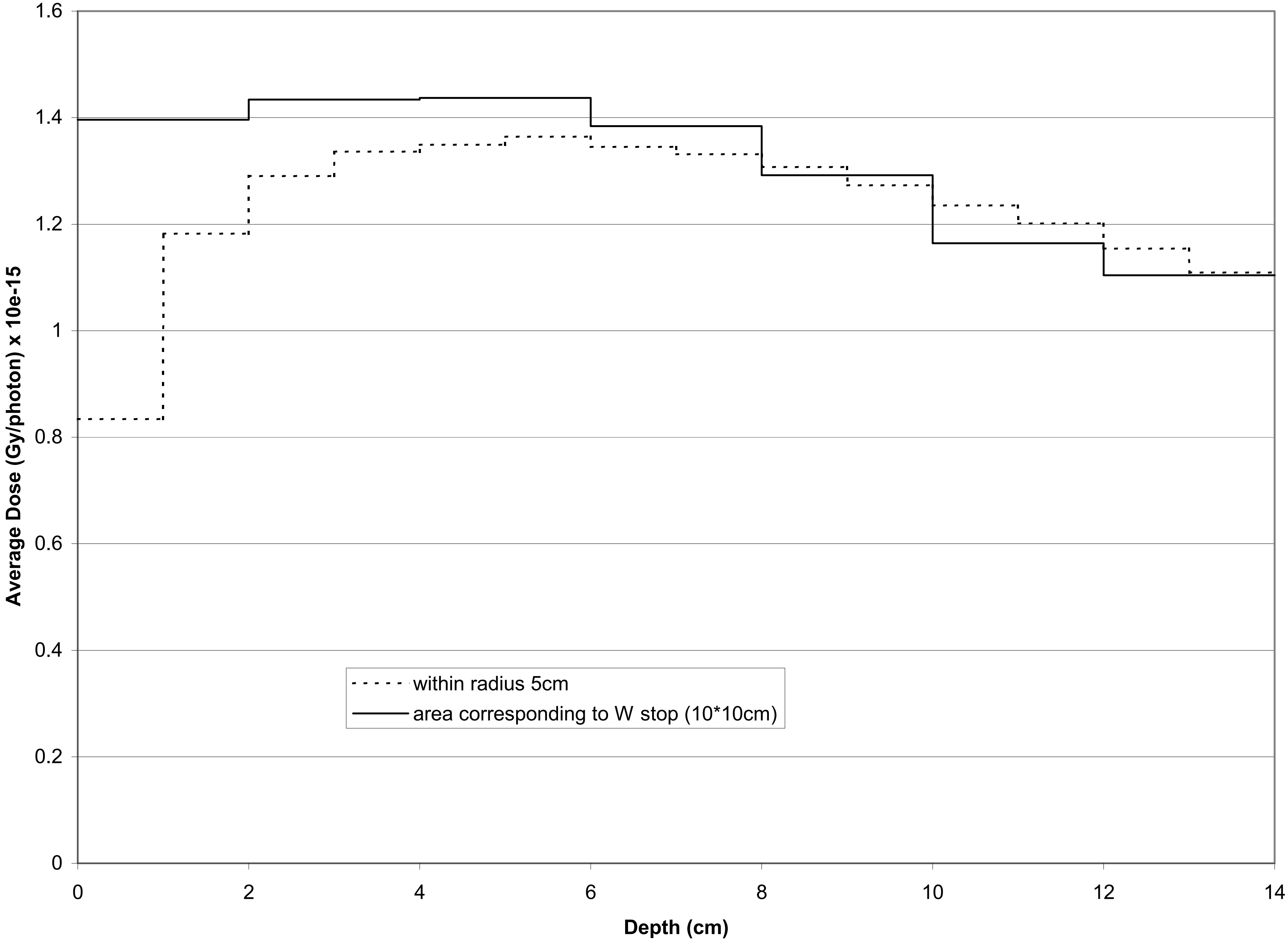

Fig. 6. Average dose as a function of depth in water phantom for Cu = 4*4*3.

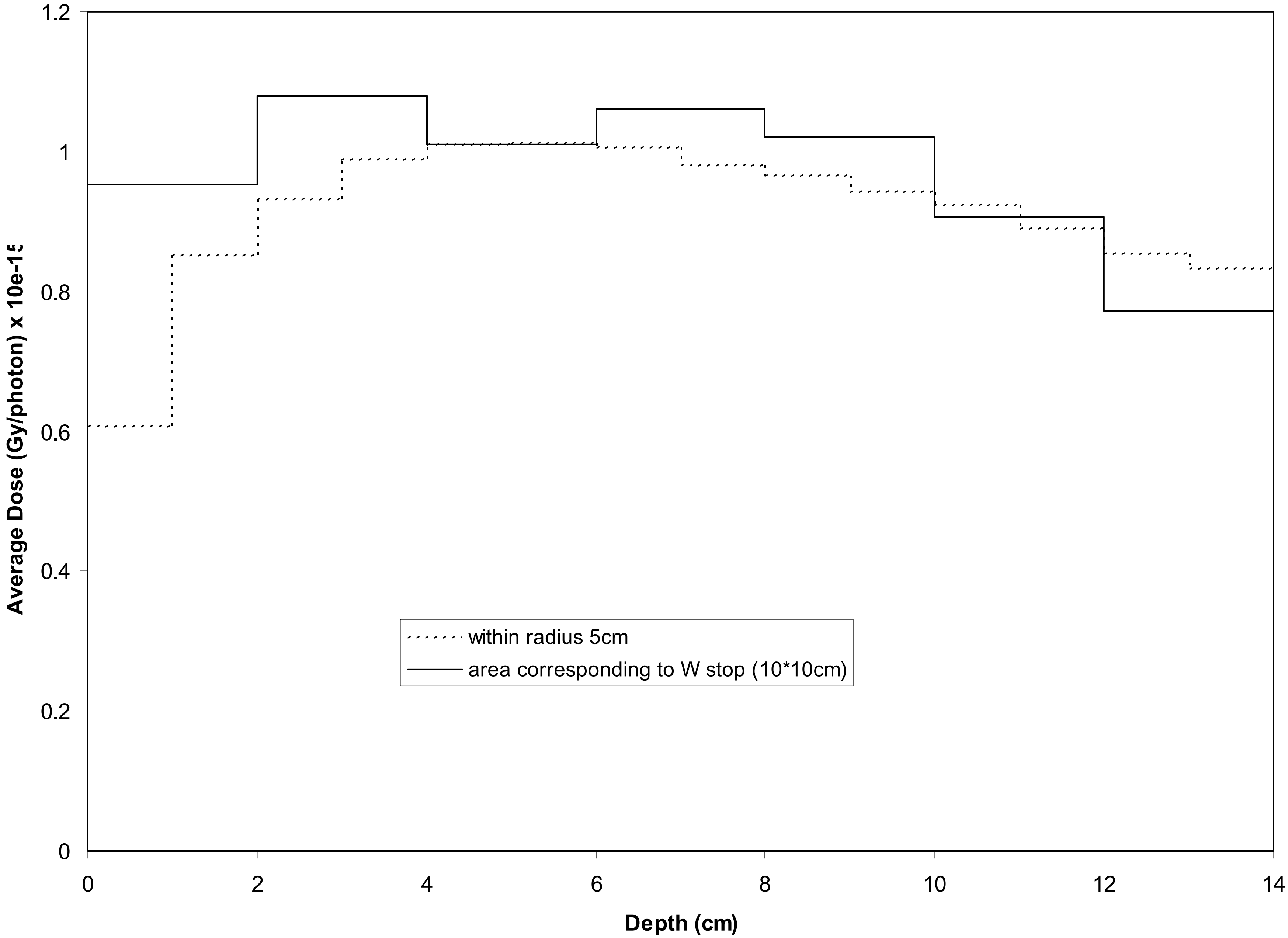

Fig. 7. Average dose as a function of depth in water phantom for Cu = 4*4*5.

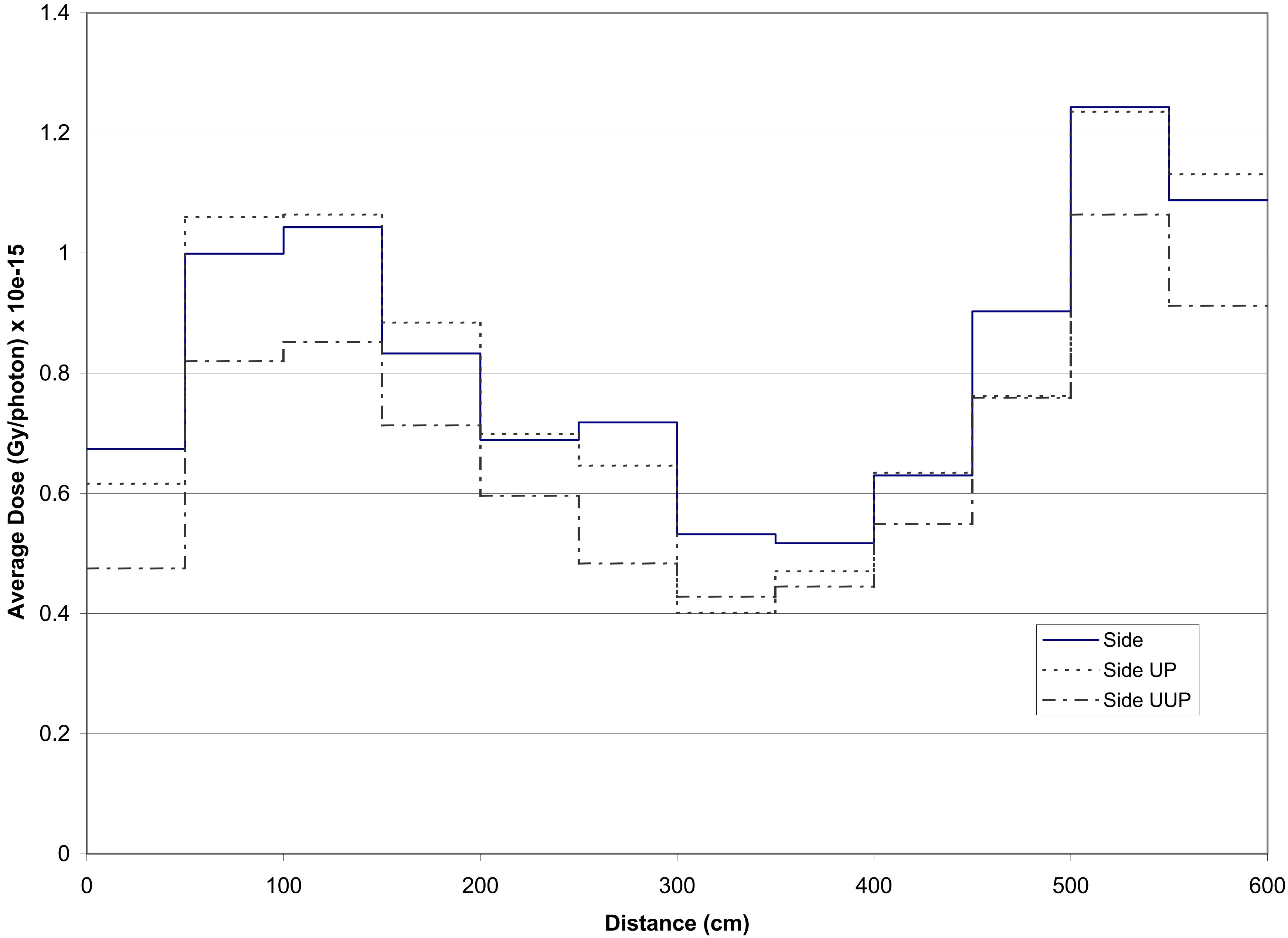

Fig. 8. Average dose along side wall of FOE with lead 3cm thick for Cu = 4*4*3.

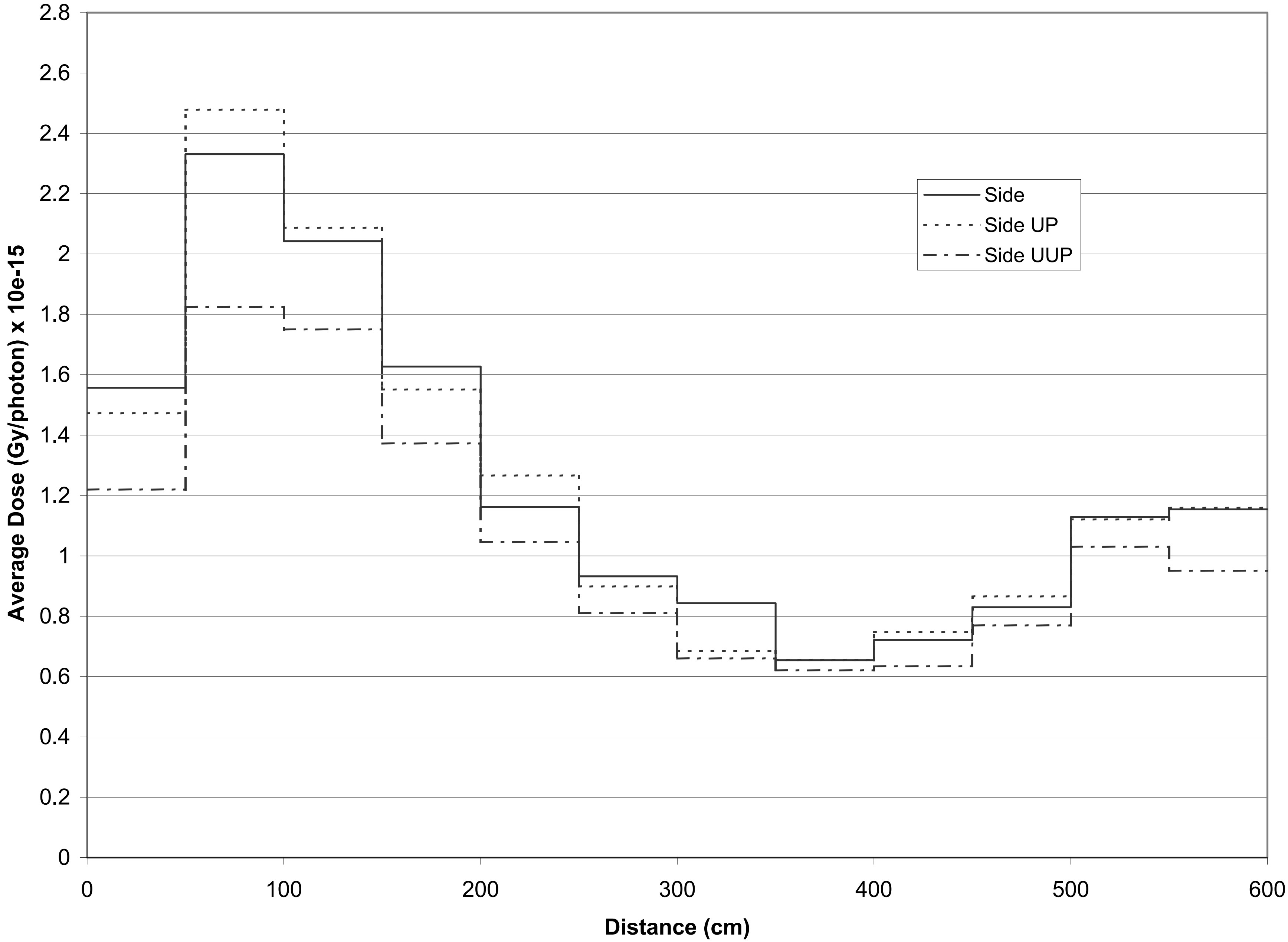

Fig. 9. Average dose along side wall of FOE with lead 3cm thick for Cu = 5*5*5.