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# A Study on Dose Distribution around Fletcher-Suit Colpostat Containing Cs-137 Source by a Computer*

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**Fletcher-Suit colpostat has an internal structure to reduce dose to bladder and rectum. Some programs were developed to calculate dose at any point in water in three dimension around the colpostat containing Cs-137 tube, to find the shielding effect to dose by the internal structure, and to draw isodose curves and iso-shielding effect curves. Computer was an IBM compatible AT with EGA card and language was MS-Basic V6.0. Material, shape and geometry of the strucure, tube and colpostat were considered in algorithm for calculation of dose. Dose rates per unit mg. Ra. eq. in water calculated by a program were stored in auxiliary memory devices and retrieved in another programs. Isodose curves on medial side shrinked. Dose distribution was not symmetric about a transverse axis bisecting the colpostat. Reduction of dose was more excessive on top side than on bottom. Iso-shielding effect curve showed that the shielding effect was higher on top side than on bottom, and that there was shielding effect over almost all area of medial side. Such results were related to both shifted position of tube in the colpostat and asymmetric distribution of active source in the tube. Maximum of shielding effect was 49% on top side and 44% on bottom side. The direction of iso-shielding effect curve was generally radial from the center of active source. In treatment planning using Fletcher-Suit colpostat, the internal structure should be considered to find precise doses to bladder and rectum, etc.**

**Key Words:** Fletcher-Suit colpostat, Cs-137 tube, Asymmetric position, Dose rate distribtuion, Shielding effect

## INTRODUCTION

Fletcher-Suit colpostat is a device being used for treatment of cervix cancer. It has an internal structure on medial side to reduce the doses to bladder and rectum, in particular. When evaluating dose around the colpostat, particularly to bladder and rectum, the doses are overestimated with no consideration of shielding effect of the internal structure. In addition, asymmetric position of tube in the colpostat[1)] and asymmetric distribution of active Cs-137 source in the tube[1~3)] are not also considered.

To get precise doses to those organs and the other sorrounding tissues, accurate dosimetry for the colpostat is essential. Several authors[1,4~7)] reported the results of dosimetry by measurement of dose distribution around such a colpostat containing Cs-137 tube. The measurements were made by means of TLD or film. Their results were, however, restricted to only a few plane. In addition, even radiation treatment planning systems still have not adopted algorithm to calculate dose considering the internal shielding effect. Some factors are decisive to making direct measurement of dose distribtuion around Fletcher-Suit colpostat difficult. They are large spacial gradient of dose, lack of geometric accuracy of dosimetric probe, difficulty in repeatibility of dosimetry setup, etc.

In radiation treatment planning system, whole data of three dimensional distribution of dose is required. To reduce error to negligible level in interpolation and extrapolation from doses at near points, sufficiently much data are required. It takes very long time to take such enormous data and to input manually the data in treatment planning system. In addition, manual process of data input may cause some significant error. To calculate, archive and use such data, to save time and to reduce making errors in input process of data, computer is necessary. The purposes of this report are to develop computer programs to calculate three dimensional dose rate per unit mg. Ra. eq. in water around Fletcher-Suit colpostat containing Cs-137 tube, and to draw isodose curve or iso-shielding effect curve on any plane parallel or perpendicular to the axis of the colopostat selected by user.

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## MATERIAL

Dose distribution in three dimension around Fletcher-Suit colpostat (3M Co., U.S.A.) containing Cs-137 source (6D6C, 3M) was studied. The colpostat was made of stainless steel of 0.05 cm thickness. External dimension of the colpostat is of 3.0 cm length and 2.0 cm diameter. It has an internal sructure at medial side designed for the purpose of reduction of doses to bladder and rectum. The structure was composed of 2 blocks of lead. The blocks were supported by a brass frame of 0.04 cm thickness and separated by 1.25 cm. Dimension of the structure is showed in Fig. 1 (directly measured data).

The active source, Cs-137 was composed of ceramic microspheres[2] and encapsulated in stainless steel tube. The tube has one eyelet that is convenient for identification of site. The axis of the tube is on the longitudinal axis of the colpostat. The center of the tube is not located at the center of the colpostat, but shifted by 0.2 cm to bottom side like as Fig 1. External dimension of cesium tube is of 2.0 cm physical length and 0.3 cm diameter. The active source is asymmetric in the tube. The lengths of end parts exterior to active source are 0.38 cm for eyelet side and 0.22 cm for the oposite. The thickness of wall is 0.1 cm. The active length of the tube and the radius of active source are 1.4 cm and 0.05 cm, respectively.

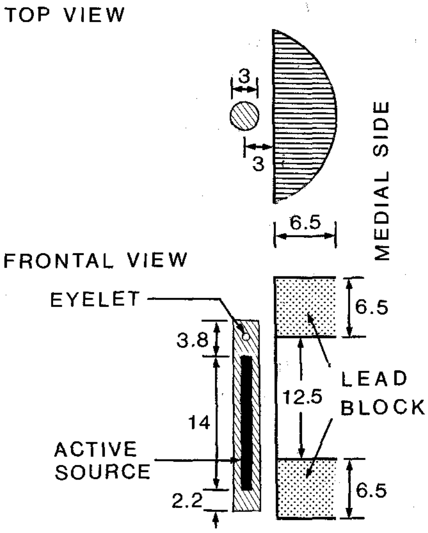

Fig. 1. Shape and dimension of Cs-137 tube (3M, 6D6C) and internal structure of Fletcher-Suit colpostat, and geometry of source. Unit is mm.

MicroSoft-Basic V6.0 was used as programing language for development of programs for calculation of dose rate per unit mg. Ra. eq. and dose distribution around Fletcher-Suit colpostat, and shielding effect of internal structure of the colpostat. Two units of programs were developed; one for dose rate calculation, another for isodose distribtuion and iso-shielding effect curve, which could be made any longitudinal and transverse plane. Any plane parallel or perpendicular to the axis of the colpostat could be selected by user to draw both dose distribution or iso-shielding effect curves using these programs. An IBM compatible AT personal computer with EGA graphic card was used.

## CALCULATION

Cylidrical coordinate system was adopted to describe geometry. The center of Fletcher-Suit colpostat was selected as its origin and Z axis was on longitudinal axis of the colpostat. X axis was on a plane longitudinally bisecting shielding blocks and directed to medial side (Fig. 2). Dose Rate D ($\rho$,

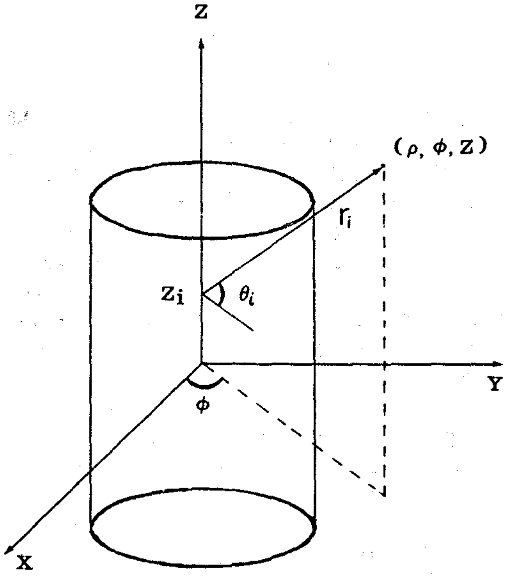

Fig. 2. Cylindrical coordinate system to describe geometry of source element and calculation point around cylindrical colpostat. The origin of the coordinate system is at the center of the colpostat. X and Z aixes are on the plane longitudinally bisecting internal structure and on the symmetrical axis of colpostat, respectively.

$\phi$, Z) at a point in water for A gm. Ra. eq. of Cs-137 source is given by

$$D\ (\rho,\phi,Z)=\frac{0.962\times 8.25\,A\,\Delta L}{L}\sum_{i=1}^{n}RDF_i\frac{e^{-\mu t}}{r_i^2}\qquad(1)$$

where 0.962 and 8.25 are roentgen-to-cGy conversion factor and specific gamma ray constant, roentgen per 1 mg Ra filtered by 0.05 cm platinum at 1 cm distance, respectively. L and n are the active length and the number of elements of linear source, respectively, and $\Delta L=L/n$. $r_i$ is the distance from source element to the point of calculation and given by

$$r_i=\sqrt{\rho^2+(Z-Z_i)^2}\qquad(2)$$

where $\rho$ and Z are radial and longitudinal coordinates of calculation point in cylindrical coordinate system and $Z_i$ the coordinate of source element.

$RDF_i$ is radial dose factor[8] for $i$th element of active source and given by

$$RDF_i=c_0+c_1\,r+c_2\,r^2+c_3\,r^3\qquad(3)$$

where $c_i$ are polynomial coefficients; $c_0=1.007$, $c_1=-5.887\times10^{-3}$, $c_2=-7.133\times10^{-4}$ and $c_3=?$[8]. $c_3$ was neglected in this report. r is path length of photon in water and given by following relations.

1) When primary photon passes through side wall of the colpostat,

$$r=r_i-\rho_{col}/\cos\theta_i,\qquad(4)$$

where $\rho_{col}$ is the radius of the colpostat. $\theta_i$ is directional angle of vector from $i$th source element to calculation point about X-Y plane and given by

$$\theta_i=\tan^{-1}((Z-Z_i)/\rho).\qquad(5)$$

2) When primary photon passes through the top of the colpostat,

$$r=r_i-(L_0/2-Z_i)/\sin\theta_i,\qquad(6)$$

where $L_0$ is the length of the colpostat.

3) When primary photon passes through the bottom of the colpostat,

$$r=r_i+(L_0/2+Z_i)/\sin\theta_i.\qquad(7)$$

In relation (1), exponential term means exponential reduction of the number of primary photons by several kind of material of the colpostat and source. $\mu t$ is the sum of the products of linear attenuation coefficient and ray path length in each material, i.e.,

$$\mu t=\sum_j\mu_j t_j\qquad(8)$$

Linear attenuation coefficients ($\mu_j$) are 0.17 $cm^{-1}$ for ceramic microspheres (2 $g/cm^3$), 0.579 $cm^{-1}$ for stainless steel[8] and 0.915 $cm^{-1}$ for lead.

It was assumed that the shape of longitudinal cross cections of a tube and colpostat was rectangular when the ray path length in each material was calculated. The ray path length in ceramic ($t_{cer}$ ($\rho$, $\phi$, Z)) is

$$t_{cer}\ (\rho,\ \phi,\ Z)=\rho_{cer}\sec\theta_i\qquad(9)$$

when primary photons crosse the inner surface of the wall of source tube, or

$$t_{cer}\ (\rho,\ \phi,\ Z)=(Z_c-Z_i)\ \csc\ \theta_i\qquad(10)$$

when the primary photons cross an end of ceramic cylinder. $\rho_{cer}$ is the radius of ceramic cylinder and $Z_c$ is the coordinate of the end of ceramic cylinder through which photons pass.

The ray path length in stainlees steel ($t_{ss}$) is the sum of pathes through tube and colpostat wall. The ray path length in stainless steel of source tube ($t_{tube}$ ($\rho$, $\phi$, Z)) is

$$t_{tube}\ (\rho,\ \phi,\ Z)=\rho_{tube}\ \sec\theta_i-t_{cer}\qquad(11)$$

when primary photons cross the lateral surface of the tube radius $\rho_{tube}$, or

$$t_{tube}\ (\rho,\ \phi,\ Z)=(Z_s-Z_i)\ \csc\theta_i-t_{cer}\qquad(12)$$

when primary photons cross an end of the tube. $Z_s$ is the coordinate of the end of the tube through which the photons pass. The ray path length in stainless steel of the wall of Fletcher-Suit colpostat is the difference of distances from a source element to points on inner and outer surfaces crossed by primary photons. The distance ($r_{out}$) from a source element to the outer surface is

$$r_{out}\ (\rho,\ \phi,\ Z)=\rho_{col}\ \sec\theta_i\qquad(13)$$

when primary photons cross the lateral wall of the colpostat, or

$$r_{out}\ (\rho,\ \phi,\ Z)=L_0|\ \csc\theta_i\ |\ /2-Z_i\ \csc\theta_i\qquad(14)$$

when primary photons cross an end of the colpostat. Distance ($r_{in}$) from a source element to the inner surface of colpostat of thickness $t_{wall}$ is

$$r_{in}\ (\rho,\ \phi,\ Z)=(\rho_{col}-t_{wall})\ \sec\theta_i\qquad(15)$$

when primary photons cross the inner sarface of the lateral wall, or

$$r_{in}\ (\rho,\ \phi,\ Z)=(L_0/2-t_{wall})\ |\ \csc\theta_i\ |\ -Z_i\csc\theta_i\qquad(16)$$

when primary photons cross the inner surface of an end of the colpostat. The total ray path length ($t_{ss}$ ($\rho$, $\phi$, Z)) in stainless steel is

$$t_{ss}\ (\rho,\ \phi,\ Z)=t_{tube}\ (\rho,\ \phi,\ Z)+r_{out}\ (\rho,\ \phi,\ Z)-r_{in}\ (\rho,\ \phi,\ Z)\qquad(17)$$

The ray path length in lead block ($t_{lead}$ ($\rho$, $\phi$, Z)) of radius $\rho_0$ and length $L_B$ and separated by $X_0$ from the axis of source tube is;

1) $t_{lead}\ (\rho,\ \phi,\ Z)=(\rho_0-X_0\ \sec\phi)\ \sec\theta_i$ (18)

when primary photons cross both longitudinal surfaces,

2) $t_{lead}\ (\rho,\ \phi,\ Z)=L_B\ |\ \csc\theta_i\ |$ (19)

when primary photons cross both cross sectional surfaces of a lead block,

3) $t_{lead}\ (\rho,\ \phi,\ Z)=(Z'-Z_i)\ \csc\theta_i-X_0\ \sec\phi\ \sec\theta_i$ (20)

when primary photons cross inner longitudinal surface and a cross sectional surface at Z′, or

4) $t_{lead}\ (\rho,\ \phi,\ Z)=\rho_0\sec\theta_i-(Z'-Z_i)\ \csc\theta_i$ (21)

when primary photons cross outer longitudinal surface and a cross sectional surface at $Z'$. The situations that primary photons pass through both lead blocks (Fig. 1), in general, should be considered. There are not, however, surh situations in the geometry of Fletcher-Suit colpostat.

The number of calculation points of dose rate in water in three dimension was $14 \times 19 \times 29$; 14 in radial, 19 in angle and 29 in longitudinal. Calculation of dose rate was made in 10 cm range in radius ($\rho$), and in both positive and negative direction of longitudinal axis (Z). The spacing between calculation points was not arranged to be uniform, but arranged to be widen with increasing distance. The spacing was arranged so that the relative maximum error between values calculated by linear interpolation method and by inverse square law is uniform. The angle ($\phi$) was based on X axis and ranged 0° to 90° at 5° intervals. Actually, lead blocks covers only some radial direction from $-\phi_B$ to $\phi_B$. $\phi_B$ is given by

$$\phi_B = \cos^{-1}(X_0/\rho_0) \qquad (22)$$

where $X_0$ is the distance from longitudinal axis of colpostat to lead block, and $\rho_0$ the radius of the block. Because $X_0$ is larger than zero, $\phi_B$ could not be 90° or larger. It was assumed that dose rate in range without reduction of primary radiation is the same as dose rate at same distance at 90°. That is,

$$D(\rho, \phi, Z) = D(\rho, 90°, Z) \text{ if } \phi > 90° \qquad (23)$$

It might take long time to calculate dose rates at such large number of points as described above with several conditions. Hence, to save time of calculation when drawing isodose curve or iso-shielding effect curve, it would be helpful to use already calculated results. Results calculated through the program for calculation of dose rate were saved to auxiliary memory devices, retrieved and used whenever necessary.

When drawing isodose curve, the coordinate of a point which is in the maximum calulated range in radial and longitudinal direction in dose rate calculation, was found by linear interpolation method. The coordinate of a point exterior to the range was found by applying inverse square law to dose rate at the nearest point in the range with calcuated dose rate.

When drawing iso-shielding effect curve, shielding effect (SE) was found by the relation.

$$SE = 100\,(1 - D(\rho, \phi, Z)/D(\rho, 90°, Z)) \qquad (24)$$

The shielding effect was described in percentage. Shielding effect was defined as the ratio of reduced dose to unshielded dose. The reduced dose means the diference of shielded and unshielded doses at same point.

## RESULTS

Fig.3 shows the isodose curves around Fletcher-Suit colpostat containing 10 mg. Ra. eq. Cs-137 tube on a longitudinal plane bisecting the internal structure, on which shielding effect is the highest. Fig. 4 shows the isodose curves on 4 transverse planes; each one at top (Z=1.5 cm) and bottom (Z=−1.5 cm) of the colpostat, and one at 1.2 cm above the top and one at 1.0 cm below the bottom. Fig. 3 shows definitely that isodose curves shrink on medial side, and are not symmetric about the longitudinal axis. Fig. 3 shows also that isodose curves shrink more excessively on top side than on bottom side. Fig. 4 shows that isodose curves shrink more excessively on area near the shielding block than the other area, and isodose curves on each plane on top side shrinked more excessively than on plane on bottom side symmetric about transverse plane bisecting the colpostat. The result showing more excessive shrinkage on top side than on bottom side agrees well with the fact that cesium tube and even active source in the tube were shifted to bottom side.

Fig. 5 shows iso-shielding effect curves around Fletcher-Suit colpostat containing Cs-137 tube on a longitudinal plane bisecting the internal structure. Generally, most iso-shielding effect curves are radially directed from the center of active source. Shielding effect is the most marked on the direction

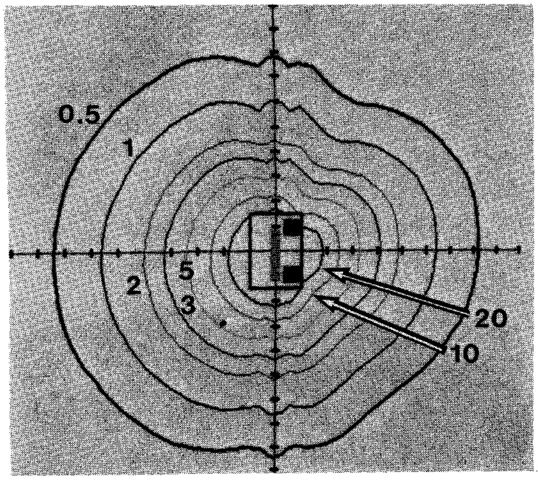

**Fig. 3.** Dose distribution around Fletcher-Suit colpostat with 10 mg. Ra. eq. Cs-137 on a longitudinal plane bisectiny the internal structure. Unit is cGy/h.

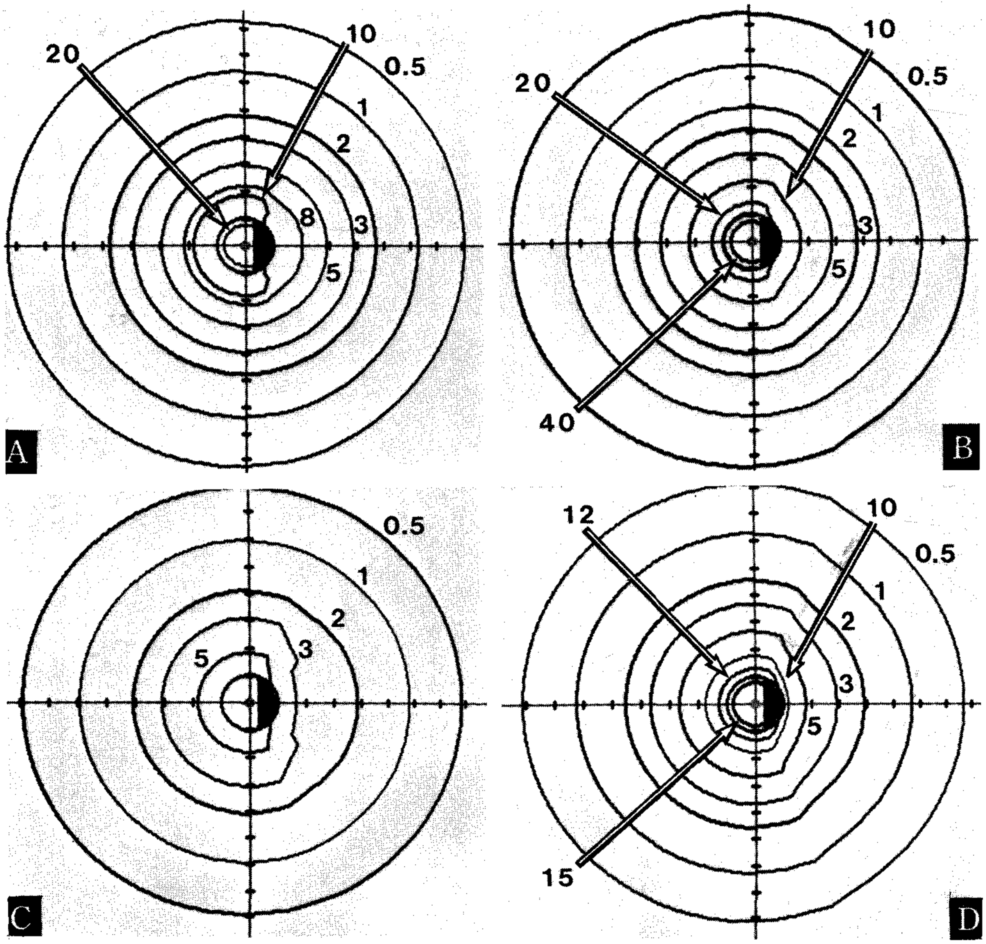

**Fig. 4.** Dose distribution around Fletcher-Suit colpostat with 10 mg. Ra. eq. Cs-137 tube on transverse plane. a) on the top surface, b) on the bottom surface, c) 1.2 cm above the top and d) 1.0 cm below the bottom. Unit is cGy/h.

linking both centers of lead block and active source. Fig. 5 also shows that on the plane there exists shielding effect over almost all area on medial side except for a part of top and bottom side. Iso-shielding effect curves are not symmetric but lean to the top side, particularly in case of lower shielding effect on wall side. Shielding effect is higher on top side than on bottom side. Maximum shielding effect is 49% on top side and 44% on bottom side at the external surface of the colpostat. It looks that such asymmetric shielding effect would be related to the asymmetric position of tube in the colpostat and the asymmetric distribution of active source in the tube.

Fig. 6 shows iso-shielding effect curves on 4 transverse planes; each one at top ($Z=1.5$ cm) and bottom ($Z=-1.5$ cm) of the colpostat, and one at 1.2 cm above the top and one at 1.0 cm below the bottom. Shielding effect is higher on top side than bottom side. There exists shielding effect only in a fan formed by the tube and the lead block. When the radius from the tube in medial side increases, over point of the maximum shielding effect, shielding effect on top side does not decrease monotonously but has a minimum value. Such pattern does not appear on bottom side. It looks that such shielding effect would be related to the position of tube and active source, and the block on bottom side would contribute to reduction of dose on top side but inverse phenomena would not occur.

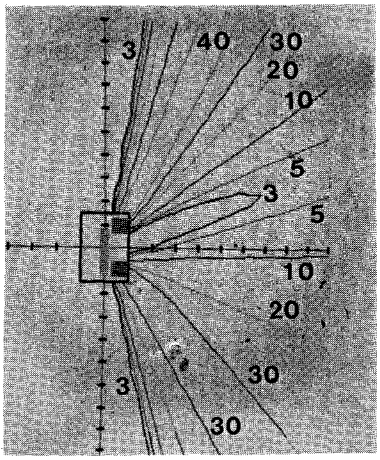

**Fig. 5.** Shielding effect curve by the internal structure of Fletcher-Suit colpostat on a longitudinal plane bisecting the internal structure. Unit is %.

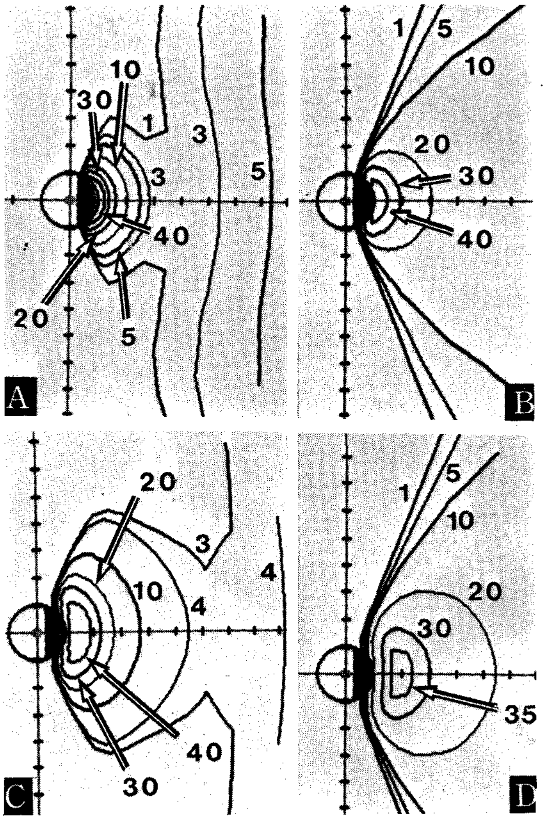

**Fig. 6.** Shielding effect curve by the internal structure of Fletcher-Suit colpostat on transverse planes. a) on the top surface, b) on the bottom surface, c) 1.2 cm above the top and d) 1.0 cm below the bottom. Unit is %.

## DISCUSSION

In this paper, the center of active source Cs-137 was considered to be shifted 0.28 cm to bottom side from the center of the Fletcher-Suit colpostat. Sharma, et al[1] reported that the center of active source was shifted by 0.3 cm to bottom side for Nuclear Associates' standard Fletcher-Suit applicator. That is very close to ours.

Drozdoff, et al[5] reported that maximum shielding effect of internal structure made of tungsten was 50% through measurement of LiF libbon in polystyrene phantom. In present study by calculation, maximum shielding effect was 49% on the surface of the top. Even though material for shielding is different, the maximum shielding effect agrees very well with Drozdoff's. It is not clear that the points with maximum shielding effect might coincide with each other in geometry.

Haas, et al[6] and Kang[7] reported the results measured by film in water phantom. Delclos, et al[4] reported the measured results with Ra-226. In our previous report[7], shielding effects were 42% on plane 1.2 cm above the top and 32% on plane 1.0 cm below the bottom. The results of Haas, et al were 15~20% on both planes, and the results of Declos, et al 27% on both planes. In this calculation, shielding effects were 45% on plane 1.2 cm above the top and 37% on plane 1.0 cm below the bottom and very close to our previous results. The results of this calculation shows the difference from the results of Haas, et al and Delclos, et al. The cause of the difference from Hass, et al. might be film and colpostat, while the cause of difference from Delclos, et al would be radiation source[9] and might be ambiguity in measurement and physical symmetry of tube in colpostat and active source in the tube.

Dose distribution on the plane 0.5 cm above the top in this paper does not agree with our previous measurement[7]. The cause might be miss in geometry. In measuring dose distribtuion with film in water phantom, films were set perpendicular rather than parallel to the transverse plane. It was not easy to find the point on film corresponding to the colpostat.

Dose distribution on a longitudinal plane bisecting the internal structure of Fletcher-Suit colpostat[7] was reported. This calculated result is very similar to previous result with some exception in region near the colpostat.

## CONCLUSION

Programs to calculate dose rate at any point in water in three dimension around the Fletcher-Suit colpostat containing Cs-137 tube, and to draw isodose curve and iso-shielding curve were developed. Any plane parallel or perpendicular to the axis of the colpostat could be selected by user to draw both dose distribution and iso-shielding effect curves using these programs. Following results were found through execution of developed programs.

1. There was reduction of dose in almost all area on medial side.
2. Shielding effect on top side was higher than on bottom side.
3. Maximum shielding effect was 49% on top side.
4. In treatment planning using Fletcher-Suit colpostat, the internal structure should be considered to find precise doses to bladder and rectum, etc.

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**＝국문초록＝**

## 컴퓨터 의한 Fletcher-Suit Colpostat 주변의 Cs-137의 선량분포에 관한 연구

서울대학교 의과대학 치료방사선과학교실

강 위 생

Fletcher-Suit 콜포스타트는 방광과 직장의 선량을 줄이기 위해 내부에 차폐물을 포함하고 있다. Cs-137튜브가 내장된 콜포스타트 주변의 물에서 임의점의 선량을 계산한 후 내부 구조에 의한 차폐효과를 구하고, 등선량곡선과 등차폐율 곡선을 그리기 위한 프로그램을 개발하였다. EGA카드를 가진 IBM호환기종 AT 컴퓨터로 MS-Basic V6.0을 이용하여 프로그램을 만들었다. 선량 계산용 알고리듬에 내부구조, 튜브, 콜포스타트의 물질, 형태 및 위치까지 고려되었다. 한 프로그램에 의해 계산된 물에서의 단위 mg. Ra. eq.당 선량율을 보조기억장치에 저장해 두고, 다른 프로그램에서 필요할 때 불러 쓰도록 하였다.

콜포스타트의 내측 선량이 감소되었으며, 상하의 선량분포가 대칭이 아님을 볼 수 있었다. 선량의 감소는 하부에 비해서 상부에서 더 현저하였으며, 차폐효과도 하부에 비해 상부에서 더 높았으며 내측 거의 전 영역에 차폐효과가 있었다. 그와같은 결과는 콜포스타트 내부에서 튜브가 한쪽으로 이동되어 있고, 튜브내에 선원의 위치가 비대칭인 점과 관련이 있었다.

최대 차폐율은 콜포스타트 상부에서 49% 하부에서 44%였으며, 등차폐율 곡선은 대체로 선원을 중심으로 하여 방사상이었다. 치료계획에서 방광 및 직장등의 정확한 선량을 구하기 위해서는 콜포스타트 내부구조에 의한 차폐 효과가 고려되어야 할 것이다.