Design and dosimetric considerations of a modified COMS plaque: The reusable "seed-guide" insert

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The Collaborative Ocular Melanoma Study (COMS) developed a standardized set of eye plaques that consist of a 0.5 mm thick bowl-like gold alloy backing with a cylindrical collimating lip. A Silastic seed carrier into which ^{125}I seeds are loaded was designed to fit within the backing. The carrier provides a standardized seed pattern and functions to offset the seeds by 1.0 mm from the concave (front) surface of the carrier. These Silastic carriers have been found to be difficult to load, preclude flash sterilization, and are a source of dosimetric uncertainty because the effective atomic number of Silastic is significantly higher than that of water. The main dosimetric effect of the Silastic carrier is a dose-reduction (compared to homogeneous water) of approximately 10%–15% for ^{125}I radiation. The dose reduction is expected to be even greater for ^{103}Pd radiation. In an attempt to improve upon, yet retain as much of the familiar COMS design as possible, we have developed a thin "seed-guide" insert made of gold alloy. This new insert has cutouts which match the seed pattern of the Silastic carrier, but allows the seeds to be glued directly to the inner surface of the gold backing using either dental acrylic or a cyanoacrylate adhesive. When glued directly to the gold backing the seeds are offset a few tenths of a millimeter further away from the scleral surface compared to using the Silastic carrier. From a dosimetric perspective, the space formerly occupied by the Silastic carrier is now assumed to be water equivalent. Water equivalency is a desirable attribute for this space because it eliminates the dosimetric uncertainties related to the atomic composition of Silastic and thereby facilitates the use of either ^{125}I and/or ^{103}Pd seeds. The caveat is that a new source of dosimetric uncertainty would be introduced were an air bubble to become trapped in this space during or after the surgical insertion. The presence of air in this space is modeled and the dosimetric impact discussed. Another unintended consequence of water equivalency is that some fluorescent x rays emitted from the gold backing can now reach the eye. These very low energy x rays were virtually eliminated by absorption in Silastic. When loaded with ^{125}I seeds the modified plaque appears to produce dose distributions that are almost the same as those of the original COMS plaque and the maximum dosimetric uncertainty introduced by an air bubble is about 2%. Dose distributions calculated for a modified plaque loaded with ^{103}Pd seeds show that dose to healthy ocular structures distal to the tumor apex can be reduced compared to ^{125}I. Clearly, it is faster and easier to glue seeds into the reusable gold seed-guide insert than it is to load the COMS-Silastic carrier. [DOI: 10.1118/1.1993828]

Key words: eye plaque, seed carrier, gold, Silastic, dosimetry, I-125, Pd-103

I. INTRODUCTION

The Collaborative Ocular Melanoma Study (COMS) compared patient survival following randomization between enucleation and ^{125}I plaque therapy. Results from the COMS group demonstrated that survival rates for these two treatments are the same.[1] Another notable contribution of the COMS was the establishment of standardized methods of plaque fabrication and dosimetry. COMS-plaque designs have been described in the literature.[2–6] Briefly, they consist of a 0.5 mm thick bowl-like gold alloy backing (77% gold, 14% silver, 8% copper, and 1% palladium[7]) with a cylindrical collimating lip and a Silastic carrier into which the ^{125}I seeds are loaded. The exterior surface of each seed is offset by 1.0 mm from the concave (front) surface of the carrier.

The *COMS Manual of Procedures*[8] recommends use of the AAPM TG-43 brachytherapy formalism[9,10] for plaque dosimetry. The basic TG-43 implementation assumes that a brachytherapy source is immersed in infinite homogeneous

water. Calculating dose to water is often an acceptable simplification because the density and effective atomic numbers of blood and soft tissues are close to that of water. Therefore the scattering and attenuation properties of soft tissues are also close to those of water. For higher energy radionuclides such as ^{192}Ir ($E_{avg} \approx 380$ keV) this is a reasonable assumption because at that energy the Compton effect dominates photon interactions with surrounding materials and Compton scattering is nearly independent of atomic number Z. For photons of low energy ($E_\gamma \leqslant 50$ keV) such as produced by ^{125}I ($E_{avg} \approx 28$ keV) and ^{103}Pd ($E_{avg} \approx 21$ keV), the probabilities of photoelectric and Compton interactions are nearly equal, but very little energy is lost in the Compton interactions.[6] The photoelectric effect becomes the dominant process by which energy is absorbed in common materials, and photoelectric attenuation is approximately proportional to the cube of the atomic number (Z) of the absorber.

The COMS Silastic carrier has been reported[4] to be made of Dow Corning medical grade elastomer, MDX4-4210. Being about 40% silicon ($Z=14$) by weight, the effective atomic number (Z_{eff}) of Silastic is close to 11, significantly higher than that of water ($Z_{eff} \approx 7.4$) with the result that photoelectric attenuation in Silastic is increased by a ratio of roughly $Z_{eff}^{3(Silastic)}/Z_{eff}^{3(water)} \approx 3$ compared to water.

The dose-modifying effects of the Silastic compared to water for ^{125}I radiation were first modeled using Monte Carlo methods by Chiu-Tsao *et al.*[4] and later measured using thermoluminescent dosimeters (TLD) by de la Zerda *et al.*[5] These researchers concluded that the effect of the Silastic insert and gold plaque was a dose reduction, compared to water, of about 10% at a distance of 10 mm on the plaque axis and about 15% at 20 mm and certain off-axis points. Astrahan[6] has recently shown that the mean linear path length through Silastic (MLPS) for COMS plaques increases from a value of about 1 mm near the center of the eye to about 3 mm in the sclera immediately in front of the plaque. The significance of these reports is that for ^{125}I radiation, use of the Silastic carrier results in a dose reduction compared to water of at least 10% in the vicinity of the tumor apex where the dose is usually prescribed, and greater than 10% at the base of the tumor and adjacent retina where the dose margin is measured. The photoelectric mass attenuation coefficient for ^{103}Pd is greater than that of ^{125}I because the average energy of ^{103}Pd radiation is less than that of ^{125}I. Therefore, if ^{103}Pd seeds[11] were to be used in a Silastic carrier it is reasonable to assume that the dose reduction compared to water would be greater than that measured for ^{125}I.

There are also logistical problems associated with the Silastic seed carriers: (1) They are difficult to load with seeds, particularly when working with forceps behind an L block. (2) If glued into a plaque with silicone adhesive they are difficult to remove and disassemble without damage to the carrier and/or plaque. (3) If not glued into the plaque, they cannot be flash sterilized. The steam can separate an unglued insert from the gold backing allowing seeds to fall out of the insert. Gas sterilization works well, but creates radiation safety issues due to the extended period of time the loaded plaques are away from the direct supervision of personnel (e.g., the medical physicist) trained in the handling of radioactive materials. Additionally, the presence of the thick Silastic insert makes surgical insertion of plaques, particularly the larger ones, more difficult than other plaque designs.

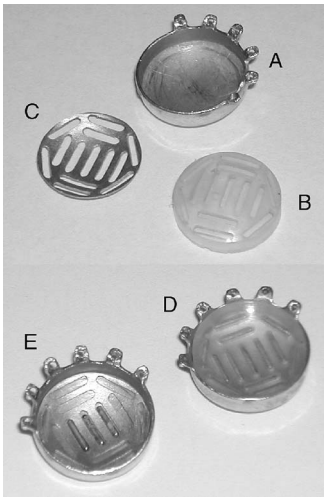


FIG. 1. (a) The gold alloy backing of a 14 mm COMS plaque; (b) the conventional Silastic seed carrier; (c) the new gold alloy thin seed-guide insert; (d) an assembled 14 mm plaque with Silastic insert and seeds; and (e) an assembled 14 mm plaque with thin seed-guide insert and three ^{125}I seeds in the central cutouts.

In comparison, some plaque designs [e.g., ^{106}Ru plaques[12] and ^{125}I plaques such as those described by Luxton *et al.*[13] and Astrahan *et al.*[14] of the University of Southern California (USC) and Nag *et al.*[15]] do not use a carrier at all. The seeds are glued directly to the backing or into shallow grooves and/or collimating slots molded into the gold backing using a thin film of cyanoacrylate adhesive. These plaque designs are generally much thinner than COMS plaques and can be flash sterilized immediately prior to surgical insertion.

This study examines the potential impact of a newly designed thin seed-guide insert and a prospective thicker insert on COMS plaque dosimetry. The thin seed guide is made of gold alloy and was developed in an effort to assure reproducible seed placement without the problems associated with Silastic. The thin insert is fundamentally a template that matches the geometry of the original COMS carrier and allows the seeds to be glued directly to the plaque backing (as is done with the USC plaques). Herein, we examine the dosimetric issues that result when these inserts are substituted for the Silastic seed carrier.

II. METHODS

The manufacturer of the COMS plaques (Trachsel Dental Studio, Rochester, MN, USA) manufactured the thin seed-guide insert used in this study. The new insert, shown in Fig. 1, is made of the same gold alloy as the plaque itself. It is a bowl about 0.3 mm in thickness with cutouts that match the seed pattern of the original Silastic carrier. The insert is positioned in the plaque as illustrated in Fig. 1(e). The insert can be rotated within the plaque in the same manner as the

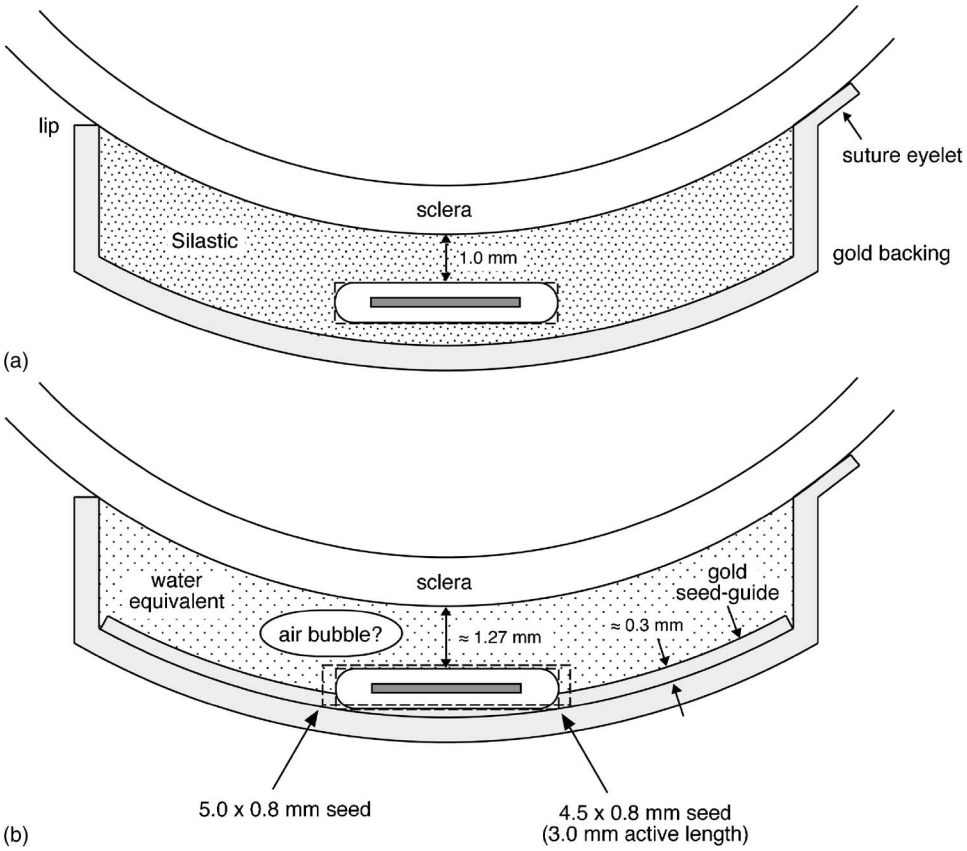


FIG. 2. (a) A 4.5×0.8 mm seed (e.g., ^{125}I model 6711) in the central slot of a conventional 14 mm COMS plaque with Silastic seed carrier. The exterior surface of the seed is offset by 1.0 mm from the concave surface of the carrier. (b) When using the thin seed-guide insert, seeds are positioned in the cutouts in the guide and both the seeds and guide are glued to the gold backing of the plaque. The precise distance between the surface of a seed and the sclera depends on the length and diameter of the seed.

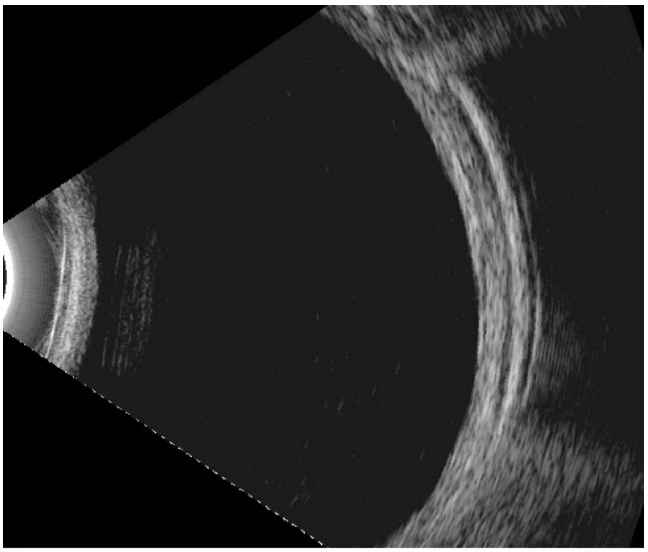
Silastic carrier enabling one to optimize the seed orientations in the manner suggested by Astrahan *et al.*[16] After an orientation has been selected, the insert and seeds are glued in place using either dental acrylic or a cyanoacrylate adhesive such as instant Krazy™ glue.

The central seed of a 14 mm plaque is illustrated in Fig. 2. When mounted in the Silastic carrier [Fig. 2(a)], the exterior surface of the seed is offset by 1.0 mm from the concave (front) surface of the carrier, which is presumably in contact with the sclera of the eye. When using the thin seed-guide insert [Fig. 2(b)], the seed is glued directly to the concave (inner) surface of the gold backing. Because the seed is a cylinder, its precise distance from the sclera will depend upon a couple of factors:

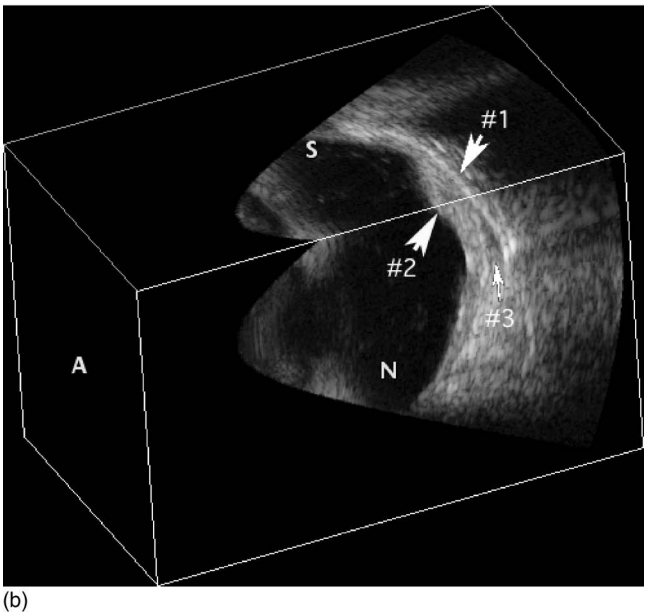
(1) The length and diameter of the seed, and to a minor extent the curvature of the seed ends, will determine where the ends of the cylinder touch the gold backing. The spacing between a typical 4.5×0.8 mm seed [e.g., OncoSeed model 6711 ^{125}I (Amersham Health, Princeton, NJ, USA) or the model 200 ^{103}Pd (Theragenics Corporation, Buford, GA, USA)] and where the front of the Silastic carrier would have been is about 1.27 mm. For the longer 5.0×0.8 mm seed [e.g., models 2301 [^{125}I] and 2335 [^{103}Pd] (Best Medical, Springfield, VA, USA)], the spacing would be about 1.18 mm.

(2) Without the Silastic carrier, the space between the seeds and sclera is presumed to be filled with radiologically water-equivalent materials such as bodily fluid and blood as illustrated in Figs. 2(b) and 3. In this situation, the plaque is entirely supported by contact between the sclera and the 0.5 mm wide lip at the cylindrical rim and the suture eyelets. The spacing between the seeds and sclera will depend to a small extent on the diameter of the plaque and how the eye is compressed where it contacts the lip. This compression will be related to the amount of pressure applied to the back of the plaque, the tightness of the suturing and the distensability of the eye wall (sclera). Figure 2(b) illustrates an ideal fit with no compression of the eye.

An existing AAPM TG-43[9,10] based ophthalmic plaque modeling and planning system [Plaque Simulator (PS), BEBIG GmbH, Berlin, Germany] was modified in order to study the dosimetry of this new thin insert and to prospectively model additional designs. The PS software uses a combination of CT, MR, and ultrasound images combined with fundus photography to build three-dimensional (3D) models of individual eyes and plaques that include details such as the suture eyelets and rotating seed carriers. From a dosimetric perspective, the PS software accounts for source linearity and anisotropy, attenuation in the Silastic carrier (compared to water) as a function of distance from the plaque and path length through Silastic, collimation of primary radiation, geometric penumbra, *L*-shell fluorescent x rays emanating from the gold plaque, and secondary scatter effects related to both the gold plaque and the eye-air interface at the cornea. The PS software and the correction factors and methods used by PS have been described in the literature.[3,6,14,16–22] The PS software was modified for this study in order to model the seed-guide insert and potential



(a)



(b)

FIG. 3. (a) *In vivo* 2D ultrasound showing a plaque with thin gold insert over the thin end of a relatively diffuse melanoma. (b) *In vivo* 3D ultrasound showing a plaque with thin gold insert and seeds (arrow #1), beneath a choroidal melanoma (arrow #2). Air bubbles trapped between the insert and the sclera in these images would reflect ultrasound and show as lucent areas surrounded by dense hyper-echoic reflections. No air bubbles are noted in the small potential space (arrow #3) between the plaque and sclera.

air trapped between the seeds and sclera. All TG-43 parameters used in this study were taken from the updated report.[10]

To study the dosimetric impact of a hypothetical air bubble [Fig. 2(b)] trapped between the plaque backing and sclera, the PS software was configured to assume that the entire space between the backing and sclera, except for the space occupied by the seeds themselves, consists of air. This is the same space that would consist of Silastic with a conventional COMS carrier, and which is assumed to be water equivalent when using the thin seed-guide insert. Air trapped in this space reduces the thickness of attenuating material

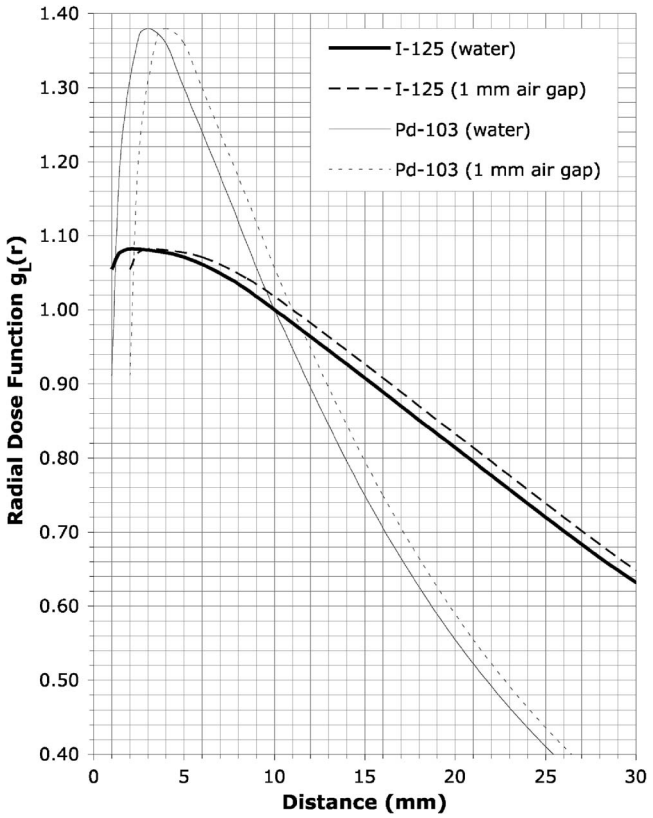


FIG. 4. In the updated TG-43 formalism (Ref. 10) scatter and attenuation are accounted for by the radial dose function $g_L(r)$ which is plotted here for model 6711 ^{125}I seeds and model 200 ^{103}Pd seeds in water. An air bubble trapped between the seeds and sclera reduces the thickness of water between the seed and dose calculation point. The dosimetric effect of a 1.0 mm thick air gap surrounding the radiation source can be approximated by shifting the $g_L(r)$ curves 1.0 mm to the right as illustrated by the dashed lines.

that radiation emanating from the seeds traverses before encountering the eye. In the updated TG-43 formalism[10] scatter and attenuation in water are accounted for by the radial dose function $g_L(r)$ which is plotted here for convenience in Fig. 4 for model 6711 ^{125}I seeds and model 200 ^{103}Pd seeds. The dosimetric effect of a small air gap surrounding the radiation source can be approximated by shifting the $g_L(r)$ curves. The primary pathlength through air between a seed and dose calculation point was used to adjust the $g_L(r)$ curves as illustrated by the dashed lines in Fig. 4. The impact of the air gap with regard to secondary scatter was not accounted for in this study. Fluorescence data are not available for plaques loaded with ^{103}Pd seeds, so the PS methods which account for fluorescence resulting from ^{125}I and which do account for the air gap were also applied as a rough estimate for the ^{103}Pd calculations of this study.

III. RESULTS

A. Geometry alone

The calculations presented in Table I isolate the purely geometric components of the dosimetric differences which result from the change in offset between seed and sclera from 1.00 mm in the Silastic carrier to 1.27 mm with the thin

TABLE I. The effect of geometry alone. Tabulated here is relative dose rate on the central axis of a 14 mm plaque for a single centrally located seed with active length 3.0 mm and physical diameter 0.8 mm (e.g., ^{125}I model 6711 or ^{103}Pd model 200) for sclera to seed offset (SO) of 1.00 mm (e.g., seed in a Silastic carrier) and 1.27 mm (e.g., seed in a thin seed-guide insert glued directly to the gold backing). Dose rate has been normalized to 1.0 at 6.0 mm which corresponds to the apex of a 5.0 mm tall tumor. Scatter, attenuation, and anisotropy are all ignored in this highly simplified calculation.

Distance (anatomy) (mm)	Seed offset (mm)		Ratio
	1.00	1.27	$SO_{1.27}/SO_{1.00}$
0.00 external sclera	21.669	17.339	0.800
1.00 base of tumor	8.612	7.597	0.882
2.00	4.522	4.193	0.927
3.00	2.763	2.641	0.956
4.00	1.857	1.811	0.975
5.00	1.331	1.317	0.989
6.00 apex of tumor	1.000	1.000	1.000
7.00	0.778	0.785	1.009
8.00	0.623	0.632	1.014
9.00	0.510	0.520	1.020
10.00	0.425	0.435	1.024
12.00	0.308	0.318	1.032
14.00	0.233	0.242	1.039
16.00	0.183	0.190	1.038
18.00	0.147	0.154	1.048
20.00 distal side of eye	0.121	0.127	1.050

insert. The geometric components account only for the shape of the source and the spatial coordinates of the source and calculation point. The radionuclide is considered to be an isotropic linear source of active length 3.0 mm located at the center of a seed. The seed is assumed to have a physical length of 4.5 mm and diameter of 0.8 mm (e.g., ^{125}I model 6711 and ^{103}Pd model 200 both satisfy these criteria). All scatter, attenuation, and anisotropy effects attributable to the specific radionuclide involved are ignored in this highly simplified calculation.

Calculations of relative dose rate (RDR) along the plaque axis (the same as the seed transverse axis in this case) are presented in Table I for the central seed of a COMS 14 mm plaque such as illustrated in Fig. 2. Shown in the table are RDR for a seed offset of 1.00 mm, 1.27 mm, and the ratio of these RDR. A distance of zero corresponds to the external surface of the sclera. These data have been normalized to a value of 1.0 at 6.0 mm from the external scleral surface. The choice of 6.0 mm distance represents a prescription to the apex of a 5.0 mm tall tumor above a 1.0 mm thick sclera. The relative dose rate between the plaque and tumor apex is observed to decrease with increased seed offset. For example, at the external sclera (0.0 mm) the dose rate is reduced by 20%. At the tumor base (1.0 mm) the relative dose rate drops by about 12%. On the other hand, at distances distal to the tumor apex the relative dose rate increases. For example, at 20 mm distance the relative dose rate increases by about 5%.

B. Full dosimetric effect

Table II lists depth dose calculations along the plaque central axis for the same COMS 14 mm plaque that has now been fully loaded with 13 seeds of equal activity. All TG-43 functions and PS extensions (e.g., attenuation in Silastic) to TG-43 were included although some did not influence this particular dose calculation. For instance, collimation by the gold backing and source anisotropy, which strongly impact off-axis calculations, have no effect on central axis calculations due to the circular symmetry of the seeds (see Fig. 1)

TABLE II. Comparison of the relative dose rate on the central axis of a 14 mm plaque fully loaded with seeds. Dose rate has been normalized to 1.0 at 6.0 mm which corresponds to the apex of a 5.0 mm tall tumor. Shown are calculations for the Silastic carrier (SC) loaded with ^{125}I seeds and the thin seed guide (SG) loaded with either ^{125}I or ^{103}Pd seeds.

Distance (anatomy) (mm)	Silastic carrier ^{125}I	Seed guide		Ratio	
		^{125}I	^{103}Pd	$SG_{I\text{-}125}/SC_{I\text{-}125}$	$SG_{Pd\text{-}103}/SG_{I\text{-}125}$
0.00 external sclera	5.949	5.349	5.997	0.899	1.121
1.00 base of tumor	3.927	3.611	4.163	0.920	1.153
2.00	2.820	2.648	2.998	0.939	1.132
3.00	2.113	2.018	2.219	0.955	1.100
4.00	1.621	1.572	1.676	0.970	1.066
5.00	1.264	1.246	1.287	0.986	1.033
6.00 apex of tumor	1.000	1.000	1.000	1.000	1.000
7.00	0.800	0.813	0.786	1.016	0.967
8.00	0.649	0.668	0.623	1.029	0.933
9.00	0.533	0.555	0.502	1.041	0.905
10.00	0.441	0.465	0.408	1.054	0.877
12.00	0.313	0.336	0.274	1.073	0.815
14.00	0.229	0.250	0.189	1.092	0.756
16.00	0.173	0.191	0.135	1.104	0.707
18.00	0.134	0.148	0.097	1.104	0.655
20.00 distal side of eye	0.105	0.117	0.071	1.114	0.607

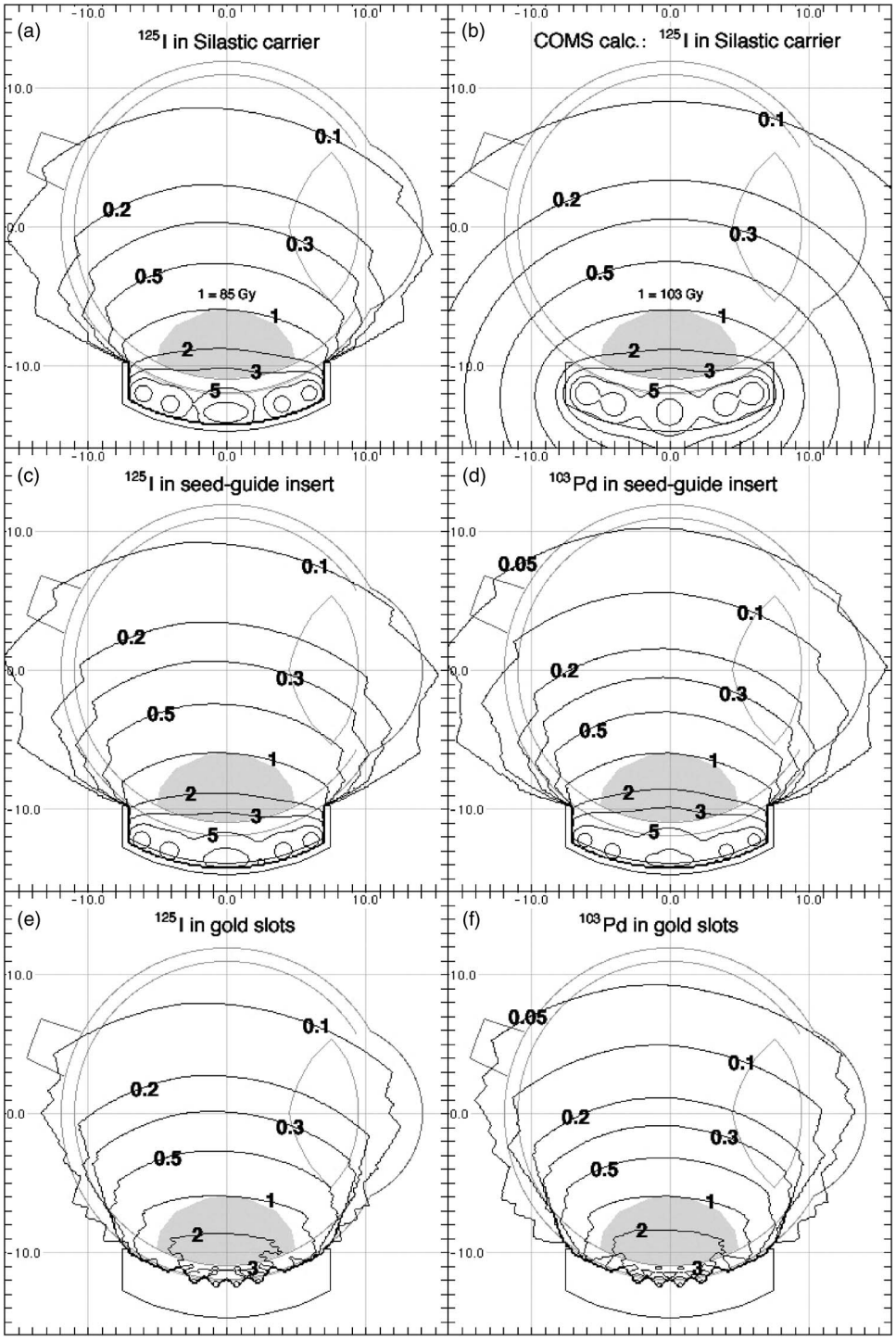


FIG. 5. 2D isodose calculations on a plane bisecting the eye and a COMS 14 mm plaque fully loaded with 13 seeds of equal activity. Plotted isodose lines have been normalized to a value of 1 at the apex of a 5 mm tall tumor. (a) A dose of 85 Gy has been prescribed to the apex of the tumor using model 6711 ^{125}I seeds in a Silastic carrier. (b) Applying the obsolete COMS dosimetric method to exactly the same ^{125}I seeds and implant duration as in (a) results in a dose of 103 Gy at the tumor apex instead of 85 Gy. The COMS method assumed that seeds are isotropic point sources, that the Silastic carrier is water equivalent, and ignored collimation by the gold backing. (c) ^{125}I seeds in the thin seed-guide insert. Because the thin insert shifts the seeds toward the back of the plaque, use of the insert results in slightly higher relative dose to ocular structures distal to the tumor apex and slightly lower relative dose to proximal regions adjacent to and underlying the tumor (e.g., sclera and retina) compared to the Silastic carrier. (d) Pd-103 seeds (model 200) in the thin insert. When ^{103}Pd seeds are substituted for ^{125}I in the seed-guide insert relative dose to structures distal to the tumor apex is noticeably reduced, but dose to proximal regions increases. (e) ^{125}I seeds in a prospective slotted gold insert. Individual seed collimation results in a more homogeneous dose distribution within the prescribed isodose surface. The seeds can be located close to the sclera because laterally directed primary radiation is reduced. The thickness of the plaque could therefore be reduced as well. (f) Using ^{103}Pd seeds in the proposed slotted insert would further reduce relative dose to regions distal to the tumor apex.

with respect to the central axis. The orientation of the central axis was parallel to the eye–air interface so that scatter modifier had no effect on the normalized data either. As in Table I, these data have been normalized to a value of 1.0 at 6.0 mm from the external scleral surface corresponding to the apex of a 5.0 mm tall tumor. When the thin seed-guide insert is substituted for the original Silastic carrier and ^{125}I seeds are used, the relative dose rate decreases by about 10% at the external sclera (0 mm) and 8% at 1.0 mm depth when dose is prescribed at 6.0 mm. At locations distal to the tumor apex the relative dose rate increases by up to 11% at 20.0 mm. Calculations were not attempted for ^{103}Pd in a Silastic carrier due to the lack of measured or modeled data for that configuration. However, when ^{103}Pd is substituted for ^{125}I when using the thin insert, the dose rate increases by 12% at 0.0 mm and by 15% at 1.0 mm. At locations distal to the tumor apex the dose rate deceases by up to 39% at 20.0 mm in comparison to ^{125}I.

Figure 5 compares two-dimensional (2D) isodose calculations on a plane bisecting the same COMS 14 mm plaque

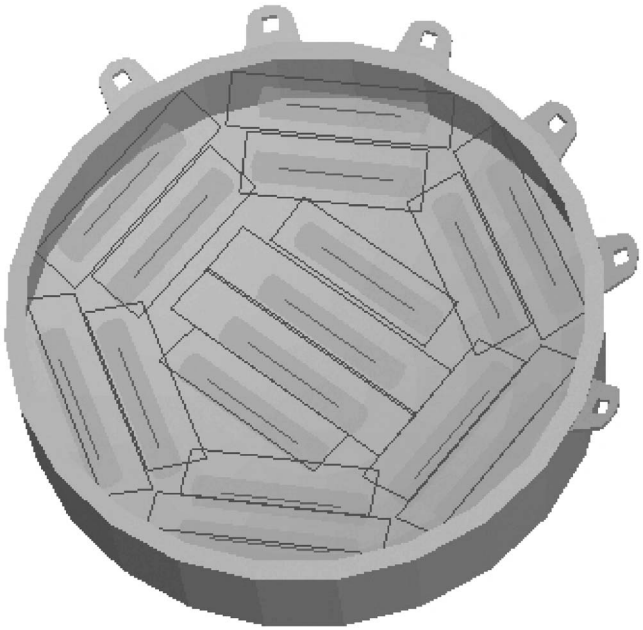


FIG. 6. Computer model of a COMS 14 mm plaque with a prospective slotted insert made of gold alloy. Illustrated within the plaque backing are sixteen ^{125}I seeds (model 6711), a linear source within each seed, and the collimating edge of each slot at the surface of the carrier. Compared to either a Silastic carrier or the thin seed-guide insert, this highly collimated hypothetical design would reduce dose to healthy ocular structures distal to the tumor apex, increase homogeneity within the prescribed isodose surface, and produce a steeper dose gradient beyond the rim of the plaque.

and an eye with a 5 mm tall tumor. The plaque is again fully loaded with 13 seeds of equal activity. A dose of 85.0 Gy was prescribed to the apex of the tumor unless otherwise noted and all PS dosimetric extensions to TG-43 are in effect except for Fig. 5(b) which uses the COMS dosimetric method for historic reference. The COMS methodology treated the seeds as isotropic point sources, required that the Silastic be considered radiologically water equivalent and ignored collimation at the plaque lip. The isodose lines in each plot have been normalized to a value of 1 at the tumor apex.

In Fig. 5(a) ^{125}I seeds (model 6711) are modeled along with the original COMS Silastic carrier. A dose of 85.0 Gy has been prescribed to the tumor apex. In Fig. 5(b) the COMS dosimetric method has been applied to exactly the same seeds and implant duration as in Fig. 5(a), yielding a dose of about 103 Gy at the apex instead of 85.0 Gy. In Fig. 5(c) ^{125}I seeds are modeled in the thin seed-guide insert. In Fig. 5(d) ^{103}Pd seeds (model 200) have been substituted for the ^{125}I seeds in the thin insert.

C. A prospective design

In Fig. 5(e) ^{125}I seeds are modeled using a prospective thick gold alloy insert based on the slotted plaque design of Astrahan *et al.*[14] This hypothetical plaque is illustrated in Fig. 6. In this design the seeds have been moved much closer to the sclera in order to increase the effects of "inverse-square" and each seed has been individually collimated in a gold slot in order to reduce laterally directed primary radiation. The collimating slots are of different dimensions in order to accommodate the circular shape and size of the plaque. In Fig. 5(f) ^{103}Pd seeds have been substituted for the ^{125}I seeds of Fig. 5(e).

D. Air under the plaque?

To study the dosimetric impact of a hypothetical air bubble trapped between the backing and sclera when using the thin seed-guide insert, treatment plans were developed for a 14 mm plaque loaded with either ^{125}I seeds or ^{103}Pd seeds. The objective of these plans was to deliver a dose rate of 1.0 Gy/h to the apex of a 5.0 mm tall tumor when the seeds are surrounded by radiologically water equivalent material. The water-like material within the backing was then entirely replaced by air with no other changes to the plan and the dose calculations repeated. This represents the limiting "worst-case" error with regard to air bubbles, i.e., that the calculation assumes water in this space and it is actually entirely air.

Table III presents central axis depth dose data for these plans. Near and distal to the apex of a 5.0 mm tall tumor, the dose rate increases by about 2% for ^{125}I seeds when air is substituted for water within the backing. The dose rate increases by about 7% when ^{103}Pd seeds are used in the same configuration. Plotted in Fig. 7 are 2D isodose calculations for these plans on a plane bisecting the plaque and eye as in Fig. 5. In practice, no air bubbles have been observed at the time of insertion or removal beneath plaques using either the thin insert (Fig. 3) or earlier versions in which seeds were glued to the backing without a seed-guide insert.[23]

IV. DISCUSSION

The ideal seed carrier for a COMS-type plaque would have the following physical properties:

(i) Z_{eff} equivalent to water,
(ii) flash sterilizable,
(iii) hold the seeds securely,
(iv) provide a reproducible pattern,
(v) easy to both load and unload with seeds,
(vi) rotate freely within the backing during assembly,
(vii) not rotate during treatment,
(viii) easy to install into the backing during assembly,
(ix) held securely within the backing during treatment,
(x) easy to remove from the backing after treatment, and
(xi) be reusable to reduce expense.

For those who wish to continue using COMS-type plaques, substituting the new thin seed-guide insert for the Silastic carrier fulfills essentially all of these requirements. It eliminates the dosimetric uncertainties related to the atomic composition of Silastic, positions the seeds in a reproducible pattern, and, in our opinion, gluing the seeds and seed guide to the backing is faster and easier than inserting the seeds into Silastic. The simplified assembly process also results in reduced radiation exposure to the person assembling the plaque. The use of cyanoacrylate or acrylic adhesive holds

TABLE III. The dosimetric effect of air trapped within a fully loaded 14 mm plaque using a thin seed-guide insert. A treatment plan was developed to deliver a dose rate of 1.0 Gy/h to the apex of a 5.0 mm tall tumor (6.0 mm total distance) assuming the space surrounding the seeds is water equivalent. The column labeled "water" is the dose rate at various distances along the plaque central axis. The column labeled "air" is the dose rate that would actually be delivered if the space surrounding the seeds were air rather than water equivalent material.

Distance (anatomy) (mm)	I-125		Ratio	Pd-103		Ratio
	Water	Air	Air/water	Water	Air	Air/water
0.0 external sclera	5.671	5.476	0.966	6.353	4.190	0.660
0.2	5.171	5.070	0.980	5.880	4.378	0.745
0.4	4.747	4.691	0.988	5.441	4.408	0.810
0.6	4.381	4.354	0.994	5.044	4.377	0.868
0.8	4.060	4.053	0.998	4.684	4.274	0.912
1.0 base of tumor	3.776	3.783	1.002	4.357	4.149	0.952
2.0	2.730	2.756	1.010	3.096	3.235	1.045
3.0	2.058	2.083	1.012	2.267	2.419	1.067
4.0	1.591	1.614	1.014	1.698	1.819	1.071
5.0	1.252	1.273	1.017	1.295	1.387	1.071
6.0 apex of tumor	1.000	1.019	1.019	1.000	1.072	1.072
7.0	0.809	0.826	1.021	0.782	0.840	1.074
8.0	0.662	0.676	1.021	0.618	0.664	1.074
9.0	0.548	0.560	1.022	0.496	0.531	1.071
10.0	0.458	0.469	1.024	0.401	0.429	1.070
12.0	0.328	0.336	1.024	0.268	0.288	1.075
14.0	0.243	0.249	1.025	0.183	0.197	1.077
16.0	0.184	0.189	1.027	0.130	0.139	1.069
18.0	0.142	0.146	1.028	0.093	0.101	1.086
20.0 distal side of eye	0.112	0.116	1.036	0.069	0.074	1.072

the seeds and guide securely to the backing during treatment yet allows the plaque to be disassembled by simply soaking it in a solvent such as acetone, allowing all of the components to be used again.

Eliminating the Silastic reduces dosimetric uncertainty associated with the carrier, but introduces a different issue found in many other plaque designs.[13–15] *L*-shell fluorescent x rays resulting from photoelectric absorption of the ^{125}I photons in the gold backing produce a small dosimetric enhancement near the surface of a plaque. This effect has been observed and measured[7,22,24–26] for various types of gold, silver and other metallic backings. These x rays have a mean energy of about 13 keV. That means they have a mean free path (MFP) in water of about 2 mm, and about 1 mm in Silastic. Chiu-Tsao *et al.*[4] confirmed that the fluorescent x rays originating from the gold backing are absorbed in the Silastic seed carrier by demonstrating the absence of dose enhancement in front of a COMS plaque. If the Silastic were replaced by water or air, the MFP for these x rays would be at least doubled and some would now reach the eye. For example, instead of a 10% reduction in dose (compared to water) to the overlying sclera or retina, there would be a few percent enhancement of dose.

The main caveat for the thin seed-guide insert is the potential for air bubbles to be trapped in the space between the backing and sclera. As illustrated in Fig. 7, the dosimetric impact of air within the plaque is to shift most of the isodose lines outward from both the plaque surface and the central axis. This is indicative of a small increase in dose at most locations in the eye as shown in Table III. However, depending on the interaction of pathlength in air, the amount of *L*-shell fluorescent x rays, and the magnitude of the "buildup" region and slope of the radial dose function (Fig. 4), dose immediately in front of the plaque could either increase or decrease by a few percent as illustrated in Table III and Fig. 7.

Conceivably, one could fabricate a COMS-like carrier or insert from water equivalent material (e.g., Solid Water™, Gammex RMI, Middleton, WI, USA) to fill the space between the seeds and sclera, but such a solid insert would reintroduce the same sterilization issues and increased difficulty of surgical insertion associated with the conventional carrier. It would certainly add to the complexity of plaque assembly. Fortunately, it has been our experience that the space formerly occupied by Silastic becomes entirely filled with bodily fluids and/or coagulated blood as illustrated in Fig. 3 and previously documented by ultrasonography and direct observation in similarly constructed plaques.[23]

Even in the unlikely event that air bubbles were to become trapped in this space, the resulting dosimetric uncertainty for ^{125}I would be small as shown in Table III and Fig. 7. If the treatment planning system assumes that the seeds are surrounded by radiologically water equivalent material, when in fact there is some air present, the result will be that the dose delivered to the tumor apex and distal side of the eye will be, at worst, a few percent higher than that predicted by the treatment planning system. This is not expected to be of clinical concern and certainly would not adversely affect

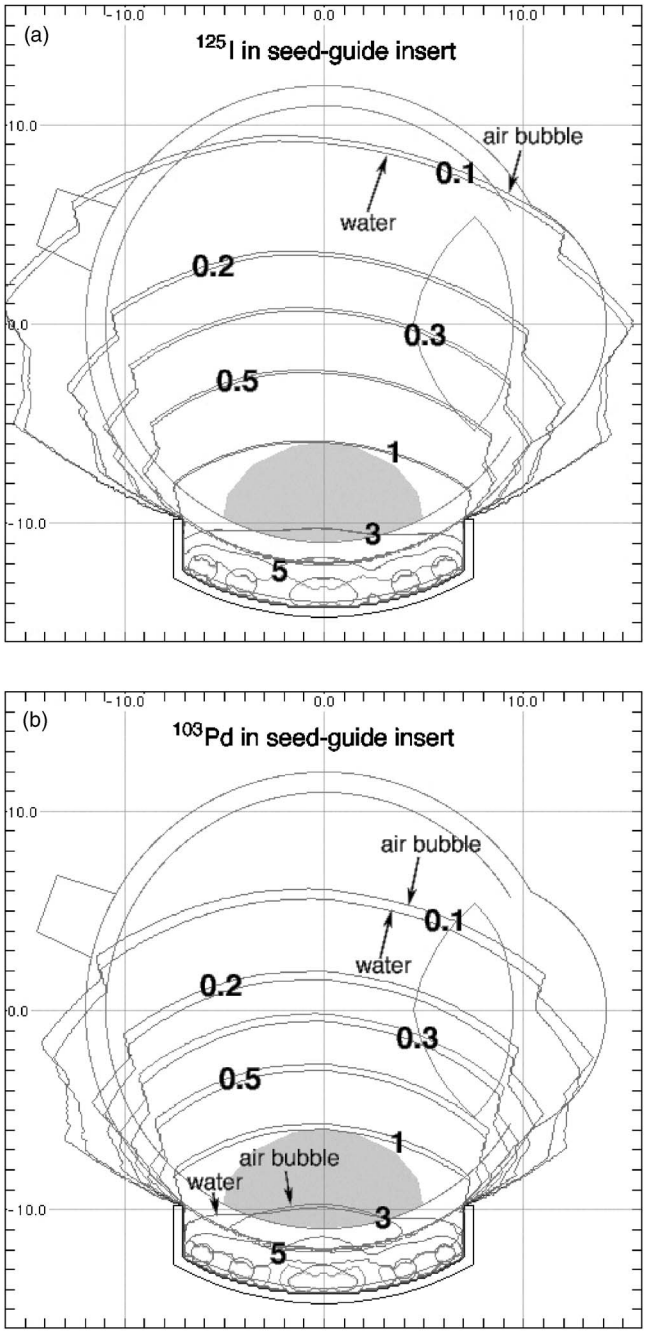


FIG. 7. Isodose plots for a 14 mm plaque fully loaded with (a) ^{125}I seeds and (b) ^{103}Pd seeds using the thin seed-guide insert. A treatment plan was developed to deliver a dose rate of 1.0 Gy/h to the apex of a 5.0 mm tall tumor when the seeds are surrounded by water equivalent material. Air was then substituted for the water equivalent material within the plaque shell with no other changes to the plan. This represents the limiting "worst-case" with regard to air bubbles. When air is present, most isodose lines shift outward from both the plaque surface and the central axis, indicative of a small increase in dose at most locations in the eye. Dose to the sclera underlying the tumor can either increase or decrease slightly.

tumor control. Therefore, we feel it is acceptable for the dose calculations to simply assume water equivalency.

Although the pattern of cutouts in the thin seed-guide insert exactly matches the slot pattern of the Silastic carrier, the seeds are now glued directly to the inner surface of the gold backing and as a result are located about 0.27 mm deeper with respect to the cylindrical lip of the backing. This results in a slightly steeper and sharper penumbral edge at the lip compared to the Silastic carrier.

A second consequence of the increased offset between the seeds and sclera when using the thin insert is that the seeds are also further away from the dose prescription point (typically the tumor apex) compared to using the Silastic carrier. Because the prescription point is not far from the radiation sources compared to the change in offset, dosimetric changes related to the geometric "inverse square" effect become noticeable. As shown in Table II the relative dose rate between the sclera and apex is reduced whereas the relative dose rate increases distal to the apex compared to the Silastic carrier. Much, but not all of the difference can be attributed to the change in geometry as shown in Table I.

Increasing the seed offset produces a more homogeneous dose distribution within the prescribed isodose surface and lowers dose to structures adjacent to the plaque, which is probably a desirable effect. The relative dose to the opposite side of the eye, however, increases by roughly 11% for ^{125}I. It is likely that these dosimetric differences are not significant in terms of tumor control, but the increased dose to the distal eye may be of concern to some clinicians. When ^{103}Pd seeds are substituted for ^{125}I seeds in the thin insert, relative dose to distal normal ocular structures is noticeably reduced, but this comes at the expense of increased dose to proximal regions both underlying the tumor and adjacent to the plaque and some increased uncertainty regarding trapped air.

Loss of vision due to late radiation effects remains a significant complication of plaque therapy.[27] Reducing the dose to normal ocular structures without compromising tumor control or introducing additional complications is therefore a desirable goal. Dose to healthy structures distal to the tumor apex, represented herein by dose to the distal side of the eye, can be reduced relative to the prescribed dose at the tumor apex through the use of seeds with a lower energy radionuclide such as ^{103}Pd instead of ^{125}I, and/or by moving the seeds closer to the sclera and thereby increasing the severity of the "inverse square" effect. Reducing the seed offset in a conventional plaque has the disadvantage of increasing dose to the sclera closest to each seed. Dose is also increased at locations adjacent to the rim of the plaque because the effectiveness of the rim as a collimator is reduced as the seeds move closer to the sclera. Other alternatives such as use of a beta emitter like ^{106}Ru are of course possible as well.

All of these approaches come at the expense of increased relative dose to the underlying sclera, base of tumor, and to retina adjacent to the tumor. Although some groups have proposed that increased basal dose might be desirable,[28] the general trend in radiation therapy practice is to seek as homogeneous a dose as practical within the prescribed isodose surface and a steep dose gradient outside that surface. The slotted plaque described by Astrahan *et al.*[14] addressed these goals by moving the sources close to the sclera and then individually collimating the sources to reduce laterally directed primary radiation which does not contribute to the tumor dose. As illustrated in Figs. 5 and 7 a similar approach

could be applied to the COMS plaque by designing a thicker gold insert with collimation properties akin to those of Astrahan's original slotted plaque. Because the seeds are positioned close to the sclera the possibility of air bubbles is eliminated and the entire plaque could be made much thinner as well. The highly collimated slotted approach offers a significant reduction of relative dose beyond the rim of the plaque and improved homogeneity within the prescribed isodose surface.

There is a minor financial disadvantage to the proposed collimated slot design in that a few more seeds are required compared to the conventional plaque (16 versus 13 seeds) for the example used in Figs. 5 and 6 in order to assure complete coverage of the tumor base because each seed is used less efficiently at short range. This is analogous to the increased use of monitor units in the delivery of intensity modulated radiation therapy compared to conventional external beam treatment.

Using ^{103}Pd seeds in a collimated slot plaque would further advance the goals of reducing dose distal to the tumor apex, homogenizing dose within the prescribed isodose surface, and creating a steep gradient outside that surface.

V. CONCLUSIONS

The thin seed-guide insert retains the original seed pattern of the COMS carrier. In our opinion, it is faster and easier to glue seeds to the gold backing using the thin insert than it is to load the seeds into the slots of a Silastic carrier. Fortuitously, the dosimetry of this modified plaque is nearly identical to that of the conventional plaque when ^{125}I seeds are used. This is because the combination of dose enhancement resulting from gold fluorescent x rays and dose reduction related to the increased offset of the seeds from the sclera is of approximately the same magnitude as the dose reduction associated with the conventional Silastic carrier. Eliminating the dosimetric uncertainties associated with Silastic also facilitates the consideration of ^{103}Pd seeds as an option for reducing dose to healthy ocular structures distal to the tumor apex.

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