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ABSTRACT

Intraocular melanoma is the most common primary malignancy of the eye. Radiation therapy using ophthalmic plaque has proved successful in the management of various ocular lesions. Although a few centres were using $^{90}Sr/^{90}Y$ plaques for shallow tumours some years ago, eye plaque therapy was not a common practice in India. A revived interest in the use of eye plaque therapy and very high cost of imported sources has led to the development and production of ^{125}I seed sources by the Radiopharmaceuticals Division, BARC. This report presents a brief description on the clinical, dosimetry and radiation safety aspects of $^{90}Sr/^{90}Y$ and $^{106}Ru/^{106}Rh$ beta ray and ^{125}I gamma ray eye plaque applicators. This report has been divided in five Sections. Section I presents general introduction of ophthalmic brachytherapy including the structure of a human eye, types of ophthalmic plaques and characteristics of radioisotopes commonly used in such applications. A brief review of sources, applicators and dosimetry of $^{90}Sr/^{90}Y$ and $^{106}Ru/^{106}Rh$ beta and ^{125}I gamma ophthalmic plaques are given in Section II and Section III, respectively. Section IV contains the single seed dosimetry data of BARC OcuProsta ^{125}I seed as well as dosimetry data of typical eye plaques loaded with BARC OcuProsta ^{125}I seed. Quality assurance and radiation safety aspects of these eye applicators are described in Section V. A proforma of the application required to be filled in by the user institution for obtaining regulatory consent to start eye plaque therapy has also been appended to this report.

CONTENTS

SECTION - I : GENERAL INTRODUCTION

Intraocular melanoma is the most common primary malignancy of the eye. Radiation therapy using ophthalmic plaque has proved successful in the management of various ocular lesions (Astrahan et al 1990 & 1997, Bosworth et al 1988, Fontanesi et al 1993). Metal ophthalmic applicators allow shielding of vital ocular structures and minimize the dose to medical personnel.

Fig. 1 illustrates the structure of a human eye. The eye has a complex structure. The eyelids keep the eye moist and shield it from intense light. The conjunctiva is a thin transparent tissue that covers the outer surface of the eye. It also secretes oils and mucus that moisten and lubricate the eye. The cornea is the transparent, dome shaped window, covering front of the eye. It is extremely sensitive. There are more nerve endings in the cornea than anywhere else in the body. The coloured part of the eye is called iris. It controls light levels inside the eye similar to the aperture of a camera. The crystalline lens is located just behind the iris. The lens focuses the incoming light onto the retina. The ciliary body lies just behind the iris.

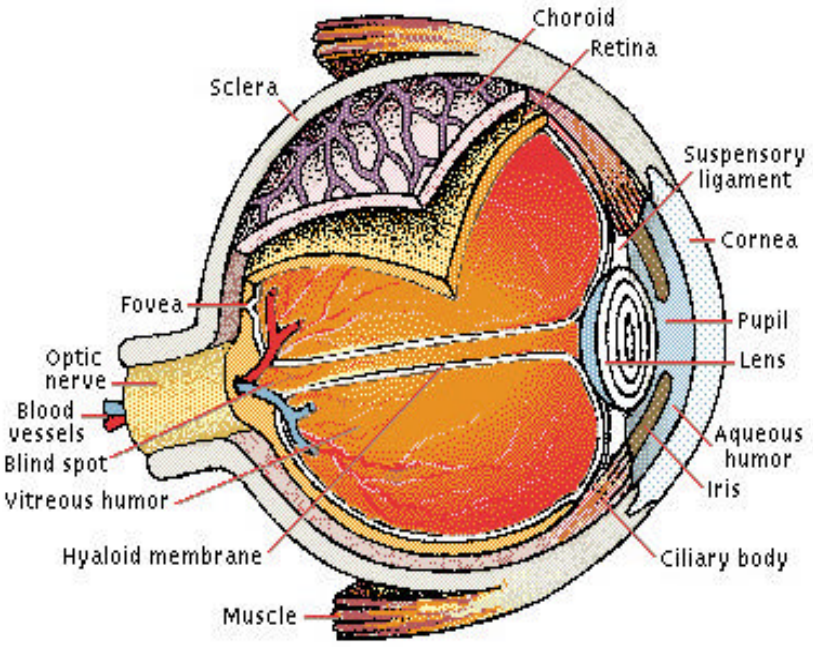

Fig. 1: The structure of a human eye

It produces aqueous humour, the clear fluid that fills the front of the eye. This fluid nourishes the cornea and the lens. The vitreous humour is a thick transparent substance that fills the centre of the eye. It comprises about two third of the eye volume, giving it form and shape. The retina is a multilayered sensory tissue that lines the back of the eye. It contains millions of photoreceptors that captures light rays and convert into electrical impulses. As the optic nerve starts here, these impulses travel along the optic nerve to the brain. The choroid contains pigmented cells that absorb any extra light which might distort the retinal picture. These cells can lose control and grow into malignant melanoma. The sclera is commonly known as the white of the eye. It is the tough opaque tissue that serves as the eye's protective outer coat. The optic nerve is attached to the sclera at the very back of the eye. Most common intraocular tumours are choroid melanoma and retinoblastoma. Choroid melanoma is the most common eye cancer in adults while retinoblastoma is the most common intraocular cancer of childhood.

Ophthalmic plaques fall into two general categories: (i) those in which sources are permanently loaded, and (ii) those in which sealed sources are temporarily loaded. In general, the choice of radionuclide depends on the target height and the availability of radionuclide. ^{226}Ra and ^{222}Rn were the first radionuclides used for such applications but are no longer in use because of the radiation hazards associated with these sources due to high energy gamma emissions. ^{60}Co ophthalmic applicators were popular for some time because of its long half-life and availability in standard sizes and shapes. The main disadvantage of ^{60}Co is its very high energy gamma emission, which makes shielding a major problem for other ocular structures and the medical personnel in the theatre. ^{32}P is a pure beta emitter and is manufactured by impregnating blotting paper with an aqueous ^{32}P solution and incorporating the paper in a flexible plastic, the size and shape of which can be adapted to suit the lesion. The short half-life of ^{32}P makes it inconvenient to use for temporary implants.

^{90}Sr/^{90}Y emerged as the most popular radionuclide for various ophthalmic applications and has been in clinical use for several years. The requirement of higher depth dose for the treatment of deep seated lesions necessitated the use of high energy β-emitting ^{106}Ru/^{106}Rh and low energy photon emitting ^{125}I sources. ^{90}Sr/^{90}Y and ^{106}Ru/^{106}Rh sources are permanently loaded onto the plaque by adsorption and are available in different sizes and shapes to meet the individual treatment requirements. ^{125}I seeds are loaded onto the eye plaque as per the treatment

prescription of the individual patient. The ^{125}I seed sources can be reused after sterilisation. Physical characteristics of radionuclides used for ophthalmic applications are listed in Table 1.

Although a few centres were using ^{90}Sr/^{90}Y plaques for shallow tumours some years ago, eye plaque therapy was not a common practice in India. A revived interest in the use of eye plaque therapy and very high cost of imported sources has led to the development and production of ^{125}I seed sources by the Radiopharmaceuticals Division, BARC. This report presents a brief description on the clinical, dosimetric and radiation safety aspects of ^{90}Sr/^{90}Y and ^{106}Ru/^{106}Rh beta ray and ^{125}I gamma ray eye plaque applications. This report has been divided in four Sections. A brief review of sources, applicators and dosimetry of ^{90}Sr/^{90}Y and ^{106}Ru/^{106}Rh beta and ^{125}I gamma ophthalmic plaques are given in Section I and Section II, respectively. Quality assurance and radiation safety aspects of these eye applicators are described in Section III. Section IV presents the single seed dosimetry data of BARC OcuProsta ^{125}I seed as well as dosimetry data of typical eye plaques loaded with BARC OcuProsta ^{125}I seed.

Table 1: Physical characteristics of radionuclides used in ophthalmic applications

Element	Radioisotope	Half-life	$E\gamma_{ave}$ (MeV)	$E\beta_{max}$ (MeV)	Plaque type
Radium	^{210}Pb (RaD) ^{210}Bi/ (RaE)	22.0 y 5.0 d	-	0.02 1.17	Permanently loaded plaques
Cobalt	^{60}Co	5.02 y	1.25	-	
Phosphorus	^{32}P	14 d	-	1.70	
Strontium Yttrium	^{90}Sr ^{90}Y	28 y 64 h	- -	0.54 2.28	
Ruthenium Rhodium	^{106}Ru ^{106}Rh	1.0 y 0.5 min.	- -	0.04 3.50 (70%) 3.10 (10%) 2.40 (10%)	
Iodine	^{125}I	59.4 d	0.028	-	Temporary loaded plaques

y = years; d = days; h = hours; min. = minutes

SECTION - II : BETA RAY OPHTHALMIC APPLICATORS

Sources and Applicators

Radionuclides generally used in beta ray ophthalmic applicators are $^{90}Sr/^{90}Y$ and $^{106}Ru/^{106}Rh$. ^{90}Sr decays to ^{90}Y with a half-life of 28 years which in turn decays with a half-life of 64 hours to ^{90}Zr. The maximum energy of beta radiation emitted during the transition from ^{90}Sr to ^{90}Y is 0.54 MeV and that from ^{90}Y to ^{90}Zr is 2.28 MeV. Therefore, ^{90}Sr in equilibrium with ^{90}Y is an ideal source for the treatment of eye lesions due to the high-energy beta emission from ^{90}Y and the long half-life of parent ^{90}Sr.

$^{90}Sr/^{90}Y$ applicators are available as permanently source loaded plaques. The front of the plaque contains a silver bonded ^{90}Sr foil covered with about 0.5 mm thick polythene which is sufficient to absorb low energy beta from ^{90}Sr. The back of the plaque is usually covered with 1 mm silver layer which absorbs almost all radiation in the backward direction. ^{90}Sr applicators are available in plane and concave shapes. The plane applicators have active and physical diameters in the range of 4 - 9 and 10 - 13 mm, respectively. The concave applicators have active diameters and radii of curvatures in the range of 6 - 18 and 10 - 15 mm, respectively. The nominal activity of the $^{90}Sr/^{90}Y$ plaque is about 370 MBq (10 mCi) which gives a dose rate of about 1 Gy/min at the surface of the applicator. The $^{90}Sr/^{90}Y$ applicators are hand held type and hence can manually be placed on the lesion to be treated. Thus, this type of applicators is easy to insert and remove.

^{106}Ru decays to stable ^{106}Pa via ^{106}Rh by beta emission. ^{106}Ru has relatively long half-life of 1 year and its daughter ^{106}Rh emits very high-energy beta radiation. The half-life of ^{106}Rh is 0.5 minute and it emits a spectrum of beta energy in which the abundance of 3.5 MeV β-radiation is about 70%.

$^{106}Ru/^{106}Rh$ plaque consists of 1 mm thick hemispherical shaped silver sheet with a radius of about 12 -14 mm and is provided with fixing plugs by which the applicator can be sutured to the sclera. A thin film of radioactive ruthenium is fixed on the concave side of the applicator shell. The active layer is gold plated and then covered with 0.1 mm thick silver window. The rear side of the applicator is about 1 mm thick silver layer which absorbs nearly 95 % of the 3.5 MeV

beta radiation. The active diameter of the plaque varies from 10 to 23.5 mm. The nominal activity of $^{106}Ru/^{106}Rh$ plaque is about 15 - 20 MBq (about 0.5 mCi) which gives a dose rate of about 120 mGy/min at the surface of the applicator (Mielcarski et al 1998). The applicator is sutured onto the sclera during treatment.

Dosimetry

The recommended quantity for specification of beta ray sources is the reference absorbed dose rate in water at a reference distance. The reference distance depends on the type of the application of the beta source. For ophthalmic applicators, the reference distance is either the surface of the applicator or 1 mm from the centre of the source (IAEA 2002).

Extrapolation chamber is the primary standard for the determination of absorbed dose rate of beta ray sources. In principle, any detector whose output can be related to absorbed dose or dose rate in tissue can be used for routine measurement of beta ray brachytherapy sources. However, due to the short range of beta ray, the detector needs to be a point-like detector. Some detectors that meet the requirement are radiochromic films, thin plastic scintillators, thin thermoluminescent dosimeters (TLDs), diode detectors, thin alanine detectors, diamond detectors and radiochromic gel dosimeters.

The experimental dosimetry of beta-ray ophthalmic applicators is particularly difficult because of the high dose gradients at the close distances which are dosimetrically significant. Curved ophthalmic applicators pose special dosimetry problems because of their geometry. The finite size of the detector, the air gap between the source and the eye surface and the metal window of the applicator contribute significantly to the dosimetric inaccuracies and the uncertainties in the estimation of absorbed dose. Monte Carlo calculations are most accurate but require relatively long computation times and precise formulation of input data. Absorbed dose calculations using integration of point dose kernels are fast and seem to be adequate for routine dosimetry of beta sources, especially in clinical dosimetry of beta-ray eye plaques. The basic steps involved in the dosimetry of beta-ray eye plaque applicators are:

(a) determination of absolute dose rate at the applicator surface or at predefined reference depth along the central axis of the source perpendicular to the surface,
(b) determination of relative dose distribution along the central axis of the source, and
(c) determination of relative dose distribution at off-axis distances.

Uniformity of beta-ray plaque sources is quantified by the percentage difference of the maximum and minimum values of relative absorbed dose rate at 1 mm in a water equivalent medium over a specified area of the source. It should preferably be less than 10%, but in any case it should not exceed 20% (IAEA 2002).

In a recent report, Soares and colleagues compared the dose rates from three beta emitting ophthalmic applicators, viz. planar plaques of $^{90}Sr/^{90}Y$ and $^{106}Ru/^{106}Rh$ and a concave plaque of $^{106}Ru/^{106}Rh$, measured using extrapolation chamber, radiochromic film, TLDs, alanine pellets, scintillation detector and diamond detector (Soares et al 2001). The $^{90}Sr/^{90}Y$ planar plaque had an active diameter of 8.6 mm. The active diameters of $^{106}Ru/^{106}Rh$ planar and concave plaques were 20.5 and 20 mm, respectively. The active side of $^{106}Ru/^{106}Rh$ concave plaque had a radius of curvature of 12 mm. The mean value of the different set of measurements yielded dose rates of 1.77 (± 14%), 2.23 (± 11%) and 7.45 (± 10%) mGy/mCi-s, respectively, for $^{106}Ru/^{106}Rh$ concave, planar and $^{90}Sr/^{90}Y$ planar applicators at the reference depth of 1 mm along the central axis. Cross et al (2001) presented a comparison of Monte Carlo calculated and measured dose distributions of these three plaques. Cross et al reported central axis depth dose data of these three plaques is also recommended by IAEA (TECDOC - 1274, IAEA 2002) which is reproduced here in Table 2.

Table 2 : Relative axial depth dose in water for three eye plaques

Depth (mm)	$^{90}Sr/^{90}Y$ Planar	$^{106}Ru/^{106}Rh$ Planar	$^{106}Ru/^{106}Rh$ Concave
0.0	1.752	1.351	1.155
0.5	1.342	1.165	1.069
1.0	1.000	1.000	1.000
1.5	0.734	0.855	0.915
2.0	0.533	0.727	0.824
3.0	0.272	0.515	0.644
4.0	0.127	0.353	0.484
5.0	0.052	0.233	0.353
7.0	-	0.090	0.170
10.0	-	0.019	0.043

SECTION - III : ^{125}I OPHTHALMIC APPLICATORS

^{125}I Seed Sources

^{125}I is produced when ^{124}Xe absorb neutrons and decays via electron capture process. ^{125}I decays with a half-life of 59.4 days and emits characteristic x-rays of energies in the range of 27.2 - 31.8 keV and gamma radiation with energy of 35.5 keV (Chiu-Tsao et. al. 1990). The HVL of ^{125}I gamma ray is about 2.25 cm in water and 0.0025 cm in lead.

^{125}I source is available in the seed form and has two distinctly different internal core designs, namely, rod/wire/cylinder type and spherical pellet type. Four different types of materials have been used for the construction of the internal core of the sources, namely, resin, ceramic, glass and high Z materials. The radioactivity is distributed within the internal core of the source either by adsorption across the surface of the internal core (surface distribution) or by absorption throughout the internal core (volume distribution). Almost all types of sources have similar external dimensions. Preferred sheathing material is titanium having thickness in the range of 0.04 to 0.08 mm. The design characteristics of the different types of ^{125}I seed sources currently available commercially are given in Figs. 2(i) and 2(ii) (Heintz et al 2001). Of these, Amersham seed models 6711 and 6702 have been considered as the reference standards and their calibrations are directly traceable to primary standards laboratory, National Institute of Standards and Technology (NIST) of USA. The model 6711 contains a 3 mm long silver rod with active material as silver iodide adsorbed on the surface, while model 6702 contains the radioisotope absorbed in 3 - 5 tiny resin spheres. Both of these seeds have 0.8 mm external diameter, 4.5 mm length and 0.05 mm titanium encapsulation.

Dosimetry of ^{125}I Seed Source

The dose distribution around ^{125}I seed source in tissue depends largely on the source construction, filtration and phantom material used. Because of the relatively low energy photons, significant absorption occurs in the titanium encapsulation and in the end welds. The phantom material used for measurement also influences the dose distribution (Meigooni et al 1988). The photon spectra and the effective energy are also different for the different types of seed sources.

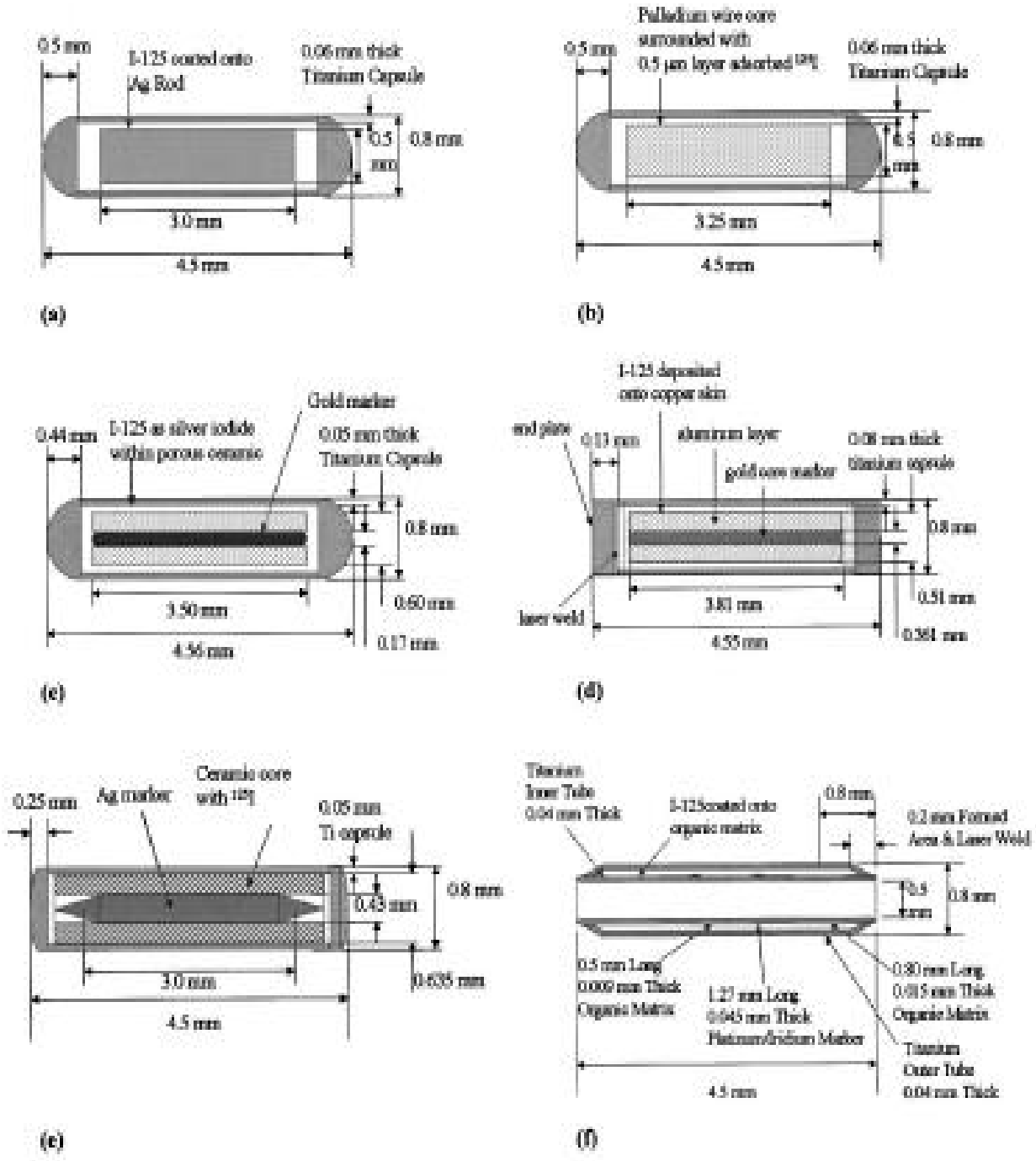

Fig. 2: (i) Cross-sectional drawings of ^{125}I seed sources with a rod/wire/cylinder internal core designs (a) Amersham Model 6711 OncoSeed, (b) Syncor PharmaSeed, (c) UroMed Symmetra, (d) SourceTech Medical ^{125}Implant, (e) Med-Tec I-Plant, (f) International Brachytherapy, Inc. InterSource^{125}.

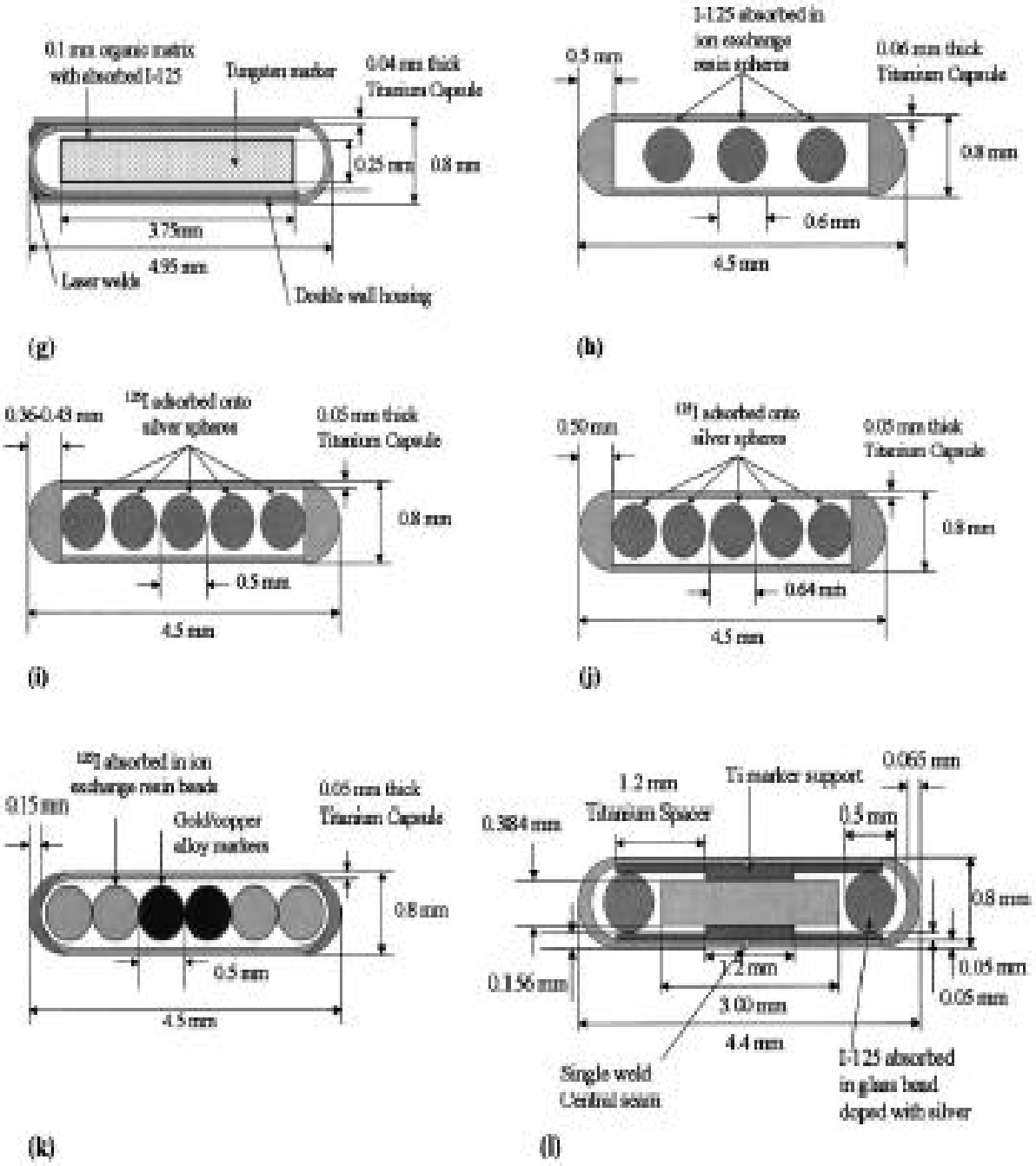

Fig. 2: (ii) Cross-sectional drawings of ^{125}I seed sources with a rod and spherical pellet internal core designs (g) Best Medical Model 2301 (h) Amersham Model 6702, (i) UroCor ProstaSeed, (j) Imagyn IsoSTAR, (k) Mentor's IoGold, and (l) DraxImage BrachySeed.

For example, Amersham model 6711 seed has an average energy of 27.4 keV due to the presence of fluorescent photons of energies 22.1 and 25.2 keV from the silver base while Amersham model 6702 seed has an average energy of 28.4 keV (Chiu-Tsao et al 1990). The characteristic x-rays of about 4.5 keV from titanium sheathing increase the air kerma rate compared to the dose rate in condensed medium. Thus, the dosimetry of ^{125}I seed is quite complex and the dose rate data published by different investigators, since its introduction in late 1960s show considerable variations (Hartman et al 1983, Chiu-Tsao et al 1990, Williamson 1988 & 1991, Williamson and Nath 1991, Sakelliou et al 1992, Williamson et al 1993, Williamson and Thomadsen 1994, and Sun et al 1996). It is, therefore, important to evaluate the dosimetric characteristics of each type of ^{125}I seed sources.

The air kerma rate calibration of ^{125}I seed is carried out by NIST using wide angle free air chamber (WAFAC). Before 1999, the NIST calibration included the contribution due to the characteristic x-rays of energy about 4.5 keV from the titanium encapsulation. As this energy does not contribute significantly to tissue dose while having a significant effect (~10%) on the calibration signal, a correction factor of 0.897 has been recommended by NIST for the ion chambers and sources calibrated prior to 1999 (Loftus 1984, IAEA 2002). Well type ionisation chambers with calibration traceable to Accredited Dosimetry Calibration Laboratories (ADCLs) of USA are commercially available for measuring the air kerma strength of ^{125}I seed sources. The dependence of calibration factor on the type of ^{125}I seeds have been reported for two of the commonly used brachytherapy well chambers, viz. HDR-1000 Plus of Standard Imaging, USA and CRC-127R of Capintec, USA (Mitch et al 2000). The variation is + 15% to -10% relative to Amersham model 6711 seed. A closer look of the data of Mitch et al reveals that the difference in calibration factor of these well chambers for the ^{125}I sources of similar construction (e.g. Amersham model 6711 seed and the Syncor PharmaSeed) is only about 3 %.

American Association of Physicists in Medicine (AAPM) Task Group No. 43 (Nath et al 1995, Rivard et al 2004) recommended a new brachytherapy dose calculation formalism using dose rate constants and other dosimetric parameters that depend on the specific source design and are directly measured or calculated for each source design. Older calculation formalisms were based upon apparent activity (A_{app}), equivalent mass of radium, exposure rate constants, and tissue attenuation coefficients. These older formalisms did not account for source-to-source

differences in encapsulation or internal construction. Except for radium, the exposure rate constants and other input parameters to these algorithms depend only on the radionuclide. As per this new formalism, the dose rate, D(r, θ) at a point (r, θ) located at radial distance r from the centre of the source and at polar angle θ relative to the longitudinal axis of the source is given as

$$D(r, \theta) = \Lambda S_K [G(r, \theta)/G(r_0, \theta_0)] g(r) F(r, \theta) \quad (1)$$

where, Λ is the dose rate constant defined as the dose rate per unit air kerma strength (S_K) at 1 cm along the transverse axis of the source in a water equivalent medium; S_K is the air kerma strength of the source; r_0 is the reference distance along transverse axis of the source = 1.0 cm; θ_0 is the reference polar angle = 90°; G(r, θ) is the geometry factor which accounts for the inverse square fall off and for distribution of radioactive material within the source ignoring absorption and scattering in the source structure; g(r) is the radial dose function which accounts for the dependence of dose on the transverse axis due to photon absorption and scattering in the medium and is equal to unity at 1 cm; and F(r,θ) is the anisotropy function which accounts for angular dependence of dose due to absorption and scattering in the encapsulation and the medium and is equal to unity on the transverse axis.

If a large number of seeds are randomly distributed, the dose rate contribution from each seed can be approximated to that from point sources. In this approximation, dose depends only on the radial distance from the source. The equation for dose around a source using point source approximation can be simplified to

$$D(r) = \Lambda S_K [g(r)/ r^2]\phi_{an}(r) \quad (2)$$

where anisotropy factor, $\phi_{an}(r)$, is the ratio of the dose rate at distance r averaged with respect to solid angle to dose rate on the transverse axis at the same distance. It may be noted that the dose rate on the transverse axis is somewhat lower using the point source approximation than the actual dose rate. The anisotropy factor is in fact valid only when point source approximation is made and average dose rate from a seed is evaluated. This is necessary for prostate permanent implants as seeds are placed in different orientations within the target volume. However, when

sources are arranged in a predefined geometry and kept at a known distance from the target volume, as in the case of eye plaque applications, line source geometry will be more appropriate. Moreover, in the recently published update of AAPM TG 43 protocol, it has strongly been recommended to maintain the consistency in the use of point or line source approximations for all brachytherapy sources (Rivard et al 2004) to avoid the inaccuracy resulting from mixing up of point and line source approximation. In other words, only those values of radial dose functions shall be used during dose rate calculation under point source approximation which has been derived using point source approximated values of geometry function. It is also recommended to rewrite equation (2) as follows

$$D(r) = \Lambda\, S_K\, [g_P(r)/\, r^2]\phi_{an}(r) \qquad (3)$$

where $g_P(r)$ is the radial dose function calculated using point source approximated values of geometry function $G_P(r, \theta) = (1/r^2)$

^{125}I Eye Plaques - Preparation, Implantation and Dosimetry

^{125}I eye plaque adopted by Collaborative Ocular Melanoma Study (COMS) Group, launched by the National Eye Institute, USA, is the most commonly used applicator for melanoma treatment (Zerda et al 1996, Chiu-Tsao 1994). COMS eye plaques are made of gold alloy and are available in five standard sizes with diameters ranging from 12 - 20 mm at 2 mm increments. The seeds are loaded into troughs moulded into a silastic seed carrier insert that fits snugly in the concave side of the gold plaque. The seed troughs are arranged in concentric rings. The layer between the bottom of the seed trough and the eye surface is 1 mm. The concave aspect of the insert has a radius of curvature of 12.3 mm designed to conform to the eye surface curvature. The metallic backing is in the form of a segment of spherical shell and terminated by a cylindrical segment which provides shielding to normal structures outside the treatment zone. Around the cylindrical segment, there are six tabs with holes for surgically suturing the plaque to the sclera.

The insert is mounted on the top of a jig with hemispherical protrusion. ^{125}I seed is picked up using tweezers and inserted into the seed trough in the seed carrier, one at a time. The seed

carrier is then covered with gold plaque, which has its inner rim coated with a thin layer of a suitable bonding agent. It should be ensured that the concave inner surface of the metallic plaque is free of glue. The plaque assembly is then transferred into a small lead container with a few holes that allow sterilising gas to pass through. The holes are lined with lead for radiation shielding. A dummy plaque of identical size and shape is also put into the same container. The container is then labelled with radiation warning sign and put in a bag for sterilisation. The sterilised bag containing the plaques is then sent to operation theatre (OT) for application on the patient.

The tumour dimensions are measured based on clinical examination using ultrasonography and in certain cases CT or MRI information. The plaque size is so chosen that the plaque adequately covers the tumour base, with a tumour-free margin. The conjunctiva is opened under local anaesthesia and the margins of the tumour are marked on the sclera. Sutures for plaque fixation are then placed over the area with the help of a dummy plaque. Once the sutures are in place, the active plaque is inserted and sutured onto the sclera. The conjunctiva is re-sutured and the patient is then shifted to the treatment room. After the dose delivery, the patient is transferred back to OT and using a similar surgical procedure, the plaque is removed, cleaned and stored.

The dose prescription point recommended for ^{125}I eye plaque therapy is 5 mm from the centre of tumour base for tumours of height up to 5 mm and from the tumour apex for tumours of height more than 5 mm. For a medium size tumour, the prescribed dose is of the order of 100 Gy delivered over the period of a few days. Data required for clinical dosimetry of ^{125}I eye plaques are: (i) absolute dose rate at the reference depth(s) along the central axis of the source perpendicular to the surface, (ii) relative dose distribution along the central axis of the source, and (iii) relative dose distribution at off-axis points.

SECTION - IV : BARC OCUPROSTA^{125}I SEED AND EYE PLAQUE

Construction, Quality Assurance and Calibration

Schematic cross sectional view of a BARC OcuProsta ^{125}I seed source is shown in Fig. 3. The source consists of 0.5 mm diameter and 3.0 mm long silver rod coated with palladium and on which ^{125}I is adsorbed. It is encapsulated in a hollow cylindrical titanium tube of 0.05 mm thick wall. Titanium, in addition to being inert towards source matrix, assures good tissue compatibility. The cap end of the cylinder is sealed by laser welding. Details about the fabrication of this source are given elsewhere (Manolkar et al 2003). The external dimensions of the seed are 0.8 mm diameter and 4.75 mm length. The maximum air kerma strength per seed is about 4.45 U (≈ apparent activity of 3.5 mCi) where, 1 U = 1 μGym^2h^{-1} = 1 $cGycm^2h^{-1}$. Physical characteristics of BARC OcuProsta ^{125}I seed source along with some of the commercially available similar-in design seed sources are given in Table 3.

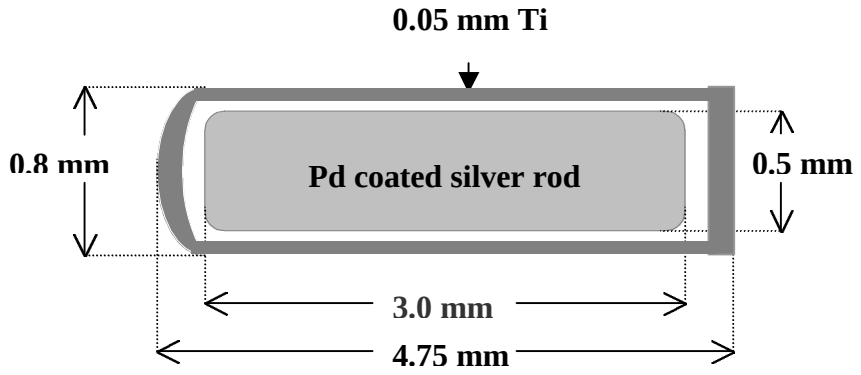

Fig. 3: BARC OcuProsta ^{125}I seed source

The sources are leak tested at the production stage by immersing the seeds at 50^0C for 5 hrs in a constant temperature bath. These sources were tested for surface contamination, using wet swipes. To measure the level of removable contamination, a very low activity ^{125}I source was used as the reference standard. A source is considered leak free if an activity less than 200 Bq is measured on swab.

Table 3: Physical characteristics of BARC OcuProsta and its comparison with some of the commercially available similar-in design ^{125}I seed sources

Parameters	^{125}I seed sources*			
	BARC OcuProsta	Amersham Model 6711	Syncor PharmaSeed	Best Model 2301
External length	4.75	4.50	4.50	4.95
External dia.	0.8	0.8	0.8	0.8
Wall thickness	0.05	0.05	0.06	0.04
End design	Laser welded semi-circle/flat	Laser welded semi-circle	Laser welded semi-circle	Laser welded single wall tube
End thickness	0.60	0.50	0.50	0.14
Internal core material	Palladium coated silver rod	Silver halide wire/rod	Palladium wire	Organic matrix coated tungsten rod
Core length	3.00	3.00	3.25	3.75
Core diameter	0.5	0.5	0.5	0.45
Activity distribution	^{125}I adsorbed onto palladium coated silver rod	^{125}I adsorbed onto silver halide rod	^{125}I adsorbed onto palladium wire	^{125}I adsorbed onto organic matrix coated tungsten wire
Radiographic marker	Silver rod	Silver wire	Palladium wire	Tungsten rod
Maximum activity (mCi)	3.50	1.00	0.64	1.00
Manufacturer	RPhD, BARC, India	Nicomed-Amersham, USA	Syncor Pharmaceuticals, China	Best Medical International, USA

*all dimensions are in mm

The uniformity of activity within the titanium encapsulation was measured using an autoradiography device, fabricated to position an array of seed sources in contact with the film. The exposure time required to obtain density in the linear region of the film response was determined by trial exposures. It was observed that an exposure time of about 40 sec per mCi activity of ^{125}I seed produce a density of about 1.0 on the Kodak X-Omat-V film.

The air kerma strength (AKS) of the OcuProsta seed was measured using SDS (PTW Freiburg, Germany) and HDR-1000 Plus (Standard Imaging, USA) well-type ionization chambers. These two well-type chambers have calibration factors in terms of $\mu Gym^2h^{-1}A^{-1}$ against Amersham model 6711 ^{125}I seed source but calibrated at two different accredited dosimetry calibration laboratories. The SDS chamber was calibrated at K&S Associates, Inc., USA while HDR-1000 Plus chamber was calibrated at University of Wisconsin, USA. The HDR-1000 Plus chamber was calibrated prior to the introduction of NIST 1999 standards and hence a correction factor of 0.897 was applied to the existing calibration factor, to bring it in conformity with the new NIST standards (Williamson et al 1999, IAEA 2000). The SDS chamber has a recent calibration factor. The AKS of OcuProsta seed measured using the two chambers differed by about 4%. The mean value of the measured AKS was used to calculate dosimetry parameters of BARC OcuProsta ^{125}I seed source. The factor recommended by AAPM for converting the strength of ^{125}I seeds from apparent mCi to AKS is 1.27 $\mu Gy.h^{-1}.m^2$/mCi, irrespective of internal construction of the source.

Single Seed Dosimetry Parameters

The dosimetry parameters of OcuProsta seed source were determined experimentally using thermoluminescent dosimeter (TLD) as well as by Monte Carlo (MC) simulation. Experimental measurements were carried out using TLD-100 (Harshaw/Bicron, USA) cylindrical rods of length 6 mm and diameter 1 mm in a specially fabricated full scatter (30x30x30 cm^3) PMMA phantom. TLD-100 is often used for brachytherapy dosimetry and has also been used extensively to characterize ^{125}I seed sources (Nath et al 1990 & 1993, Meigooni et al 2000, Popescu et al 2000). PMMA was used as the phantom material because of its local availability, low cost and ease of machining. It has also been demonstrated as a reasonably suitable phantom material for dosimetry of ^{125}I sources (Meigooni et al 1988). Central slab of

this phantom is 6 mm thick and contain a circular hole where a circular PMMA disc of diameter 12 cm can be positioned. Three such PMMA discs with different patterns of holes to accommodate TLD rods were fabricated for measurement of dose distribution around the OcuProsta seed. The dose response curve for TLD rods was obtained by exposing them in a ^{60}Co gamma rays beam (Th780E, MDS Nordian, Canada) and was found to be linear in the dose range of 0.1 - 1.5 Gy. Response of TLD rods in the region of ^{125}I energy relative to ^{60}Co gamma rays was evaluated using 75 kVp x-rays (RT 250, Philips Medical Systems, UK). TLD response corresponding to 75 kVp x-rays, 1.0 mm Al filter, which corresponds to an effective energy of 35 keV, was found to be 40% higher than ^{60}Co gamma rays. Therefore, an energy correction factor of 1.40 was used to determine the absorbed dose from ^{125}I source. Uncertainties in the measurement of dose distribution from ^{125}I source using TLD rods include uncertainty of AKS measurement (~5%), TL output to dose conversion factor (~2%), energy correction factor relative to ^{60}Co gamma rays (~2%), positional uncertainty (~2%) and dose conversion from perspex to water (~2%). The combined standard uncertainty in the experimental measurement works out to be about 6.5%.

The well established Monte Carlo (MC) simulation code MCNP version 3.1 (Los Alamos MCG 1983) was used to calculate AKS and absolute dose rates in water around the BARC ^{125}I OcuProsta seed source. The dose distribution generated using MC simulation is shown in Table 4. Estimation of AKS and dose-rate in water involved suspension of source at the center of 500 cm diameter void and 30 cm diameter liquid water spheres, respectively. In the MC calculations, (r, θ) polar coordinate system was adopted. The photon energy fluences were scored initially at each (r, θ). The energy fluences thus scored were subsequently converted into air kerma and water kerma using mass energy absorption coefficients of air and water (Hubbell and Seltzer 1995), respectively. As charged particle equilibrium was assumed to exist, the water kerma was approximated to absorbed dose to water. The ^{125}I energy spectrum required for MC calculations was taken from ICRP (1983). In the MC calculations 1×10^7 to 4×10^7 photon histories were simulated. The contribution from titanium (Ti) characteristic K x-rays (4.5 keV) resulting from photoelectric absorption of primary ^{125}I x-rays in the Ti capsule was suppressed in the Monte Carlo calculations. This is because the contribution by these x-rays to dose rate in water is negligible. The statistical uncertainties associated with the MC estimated dose rate values were within ± 0.5 %.

The dosimetry parameters required for calculation of dose rate at a point in tissue (see Eq.1) were derived using the definitions recommended in AAPM TG-43/43U1 reports (Nath et al 1995, Rivard et al 2004). The dose rate constant, Λ, is defined as the dose rate per unit air kerma strength at 1 cm along the transverse axis of the source in a water equivalent medium. It is expressed in units of cGy h^{-1} U^{-1}. Hence, the dose rate constant was derived using the relation

$$\Lambda = D\,(r_0, \theta_0)\,/S_K \qquad (4)$$

where, $D(r_0, \theta_0)$ is the dose rate at r_0 = 1.0 cm, $\theta = 90^0$ and S_K is the AKS of the source.

Radial dose function, g(r), accounts for the dose fall off on the transverse axis of the source due to photon absorption and scattering in the medium and is equal to unity at 1 cm. It is expressed as

$$g(r) = \frac{D(r,q_0)G(r_0,q_0)}{D(r_0,q_0)G(r,q_0)} \qquad (5)$$

where, $D(r, \theta_0)$ and $D(r_0, \theta_0)$ are the dose rates at r and r_0 along the transverse axis of the source.

Anisotropy Function, F(r, θ), accounts for angular dependence of dose due to absorption and scattering in the encapsulation and the medium and is equal to unity at the same radial distance along the transverse axis. It is given as

$$F(r,q) = \frac{D(r,q)G(r_0,q_0)}{D(r,q_0)G(r,q)} \qquad (6)$$

Experimental values of F(r, θ) were determined using measured mean dose rates at polar angles ranging from 0 to 360^o while MC values of F(r, θ) were obtained using calculated mean dose rates at polar angles ranging from 0 to 180^o. Assuming cylindrical and radial symmetry, dose rates of four quadrants was averaged to evaluate the anisotropy functions for polar angles 0 to 90^0. The anisotropy function for different polar angles and radial distances are given in Table 5. Anisotropy factor $\phi_{an}(r)$ was calculated using the relation

$$f_{an}(r) = \frac{\int_0^{\Pi} \dot{D}(r,q)\sin(q)\,dq}{2\dot{D}(r,q_0)} \qquad (7)$$

The geometry function, G(r, θ), describes the inverse square fall off and account for distribution of radioactive material within the source, ignoring absorption and scattering in the source structure. It is given as:

$G_P(r, \theta) = 1/r^2$ for point source approximation

$G_L(r, \theta) = \beta/L\ r \sin\theta$ for line source approximation

where, L is the active length of the source and β is the angle subtended by the active ends of the source at point (r, θ). The geometry factor calculated for BARC ^{125}I seed source of active length 3.0 mm is given in Table 6.

As stated earlier, Amersham model 6711 seed is considered to the reference standard for similar model seeds. The dose rate constant, anisotropy constant and radial dose function of the BARC OcuProsta ^{125}I seed have been compared with those of Amersham model 6711 seed. This comparison of dosimetry parameters of BARC OcuProsta and Amersham model 6711 seeds have been shown in Table 7 and Table 8.

Table 4: Monte Carlo calculated dose rate per unit air kerma strength at different radial distance (cm) from BARC OcuProsta ^{125}I seed source

Polar angle, θ (deg.)	Dose rate, D(r, θ) (cGy/hr)						
	r = 0.5	r = 1.0	r = 1.5	r = 2.0	r = 3.0	r = 4.0	r = 5.0
10	1.546	0.469	0.195	0.113	0.042	0.020	0.010
20	2.668	0.674	0.278	0.148	0.054	0.024	0.012
30	3.314	0.796	0.326	0.169	0.060	0.027	0.013
40	3.678	0.869	0.355	0.183	0.065	0.029	0.014
50	3.880	0.916	0.374	0.192	0.068	0.030	0.015
60	3.987	0.947	0.387	0.198	0.070	0.031	0.015
70	4.038	0.964	0.395	0.202	0.071	0.031	0.015
80	4.063	0.974	0.400	0.204	0.072	0.032	0.015
90	4.069	0.978	0.401	0.204	0.072	0.031	0.015

Table 5: Anisotropy function for BARC OcuProsta ^{125}I seed source

Polar angle, θ (deg.)	Anisotropy function, F(r, θ)							
	r = 0.50	r = 1.00[a]	r = 1.00	r = 1.50	r = 2.00	r = 3.00	r = 4.00	r = 5.00
0	0.146	0.244	0.256	0.302	0.363	0.429	0.471	0.499
10	0.338	0.496	0.466	0.481	0.548	0.580	0.619	0.637
20	0.590	0.664	0.672	0.685	0.721	0.738	0.761	0.778
30	0.746	0.798	0.796	0.805	0.823	0.833	0.849	0.852
40	0.845	0.916	0.874	0.878	0.891	0.895	0.906	0.905
50	0.911	0.907	0.926	0.929	0.936	0.938	0.947	0.945
60	0.954	0.926	0.962	0.962	0.966	0.966	0.972	0.966
70	0.980	0.956	0.983	0.984	0.987	0.986	0.990	0.987
80	0.996	1.029	0.995	0.996	0.997	0.994	1.002	0.998
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

[a]TLD measured data

Table 6: Ratio of geometry function (line source approximation) for BARC OcuProsta ^{125}I seed source of active length 3.0 mm (r_0 = 1 cm, θ_0 = 90°)

Polar angle, θ (deg.)	Ratio of geometry function, G(r, θ)/G(r_0, θ_0)								
	r = 0.3	r = 0.5	r = 1.0	r = 1.5	r = 2.0	r = 2.5	r = 3.0	r = 4.0	r = 5.0
10	14.661	4.407	1.029	0.452	0.253	0.162	0.112	0.063	0.040
20	13.998	4.354	1.026	0.451	0.253	0.162	0.112	0.063	0.040
30	13.159	4.276	1.022	0.451	0.253	0.162	0.112	0.063	0.040
40	12.335	4.187	1.017	0.450	0.252	0.161	0.112	0.063	0.040
50	11.627	4.099	1.012	0.449	0.252	0.161	0.112	0.063	0.040
60	11.074	4.022	1.007	0.448	0.252	0.161	0.112	0.063	0.040
70	10.683	3.963	1.003	0.447	0.252	0.161	0.112	0.063	0.040
80	10.452	3.926	1.000	0.446	0.251	0.161	0.112	0.063	0.040
90	10.376	3.913	1.000	0.446	0.251	0.161	0.112	0.063	0.040

Table 7: Dose rate constant (DRC) and anisotropy constant for BARC OcuProsta ^{125}I and Amersham model 6711 seeds

Seed model	Technique of evaluation	DRC ($cGyh^{-1}U^{-1}$)	Anisotropy constant
BARC OcuProsta	TLD measurements	0.950 ± 0.065	0.880
	MC simulation	0.972 ± 0.005	0.902
Amersham model 6711	MC simulation	0.973 ± 0.005	0.930

Table 8: Radial dose function for BARC OcuProsta ^{125}I and Amersham model 6711 seeds

Radial distance, r (cm)	Radial dose function, g(r)		
	BARC OcuProsta		Amersham 6711
	Measured (TLD)	MC	
0.5	1.100	1.067	1.04
1.0	1.000	1.000	1.00
1.5	0.875	0.915	0.926
2.0	0.815	0.827	0.832
2.5	0.744	0.738	0.731
3.0	0.687	0.655	0.632
4.0	0.529	0.507	0.463
5.0	0.367	0.386	0.344

Dosimetry of OcuProsta Loaded Eye Plaques

A computational programme was written in Quick Basic language (QB 4.5) to generate data for the dosimetry of eye plaque therapy using the dose distribution data of BARC OcuProsta ^{125}I seed. Dose computations were done for plaque diameters of 12, 14, 16, 18 and 20 mm. The radius of curvature of the plaque taken in this calculation was 12.3 mm. The number of seeds used for each plaque was 8, 12, 16, 20 and 24, respectively. End co-ordinates of the seed sources were determined assuming centre of the plaque curvature as the origin and the Z co-ordinate along the line passing through the centre of the plaque and perpendicular to its plane. A typical source loading pattern used for 14 mm plaque is shown in Fig. 4.

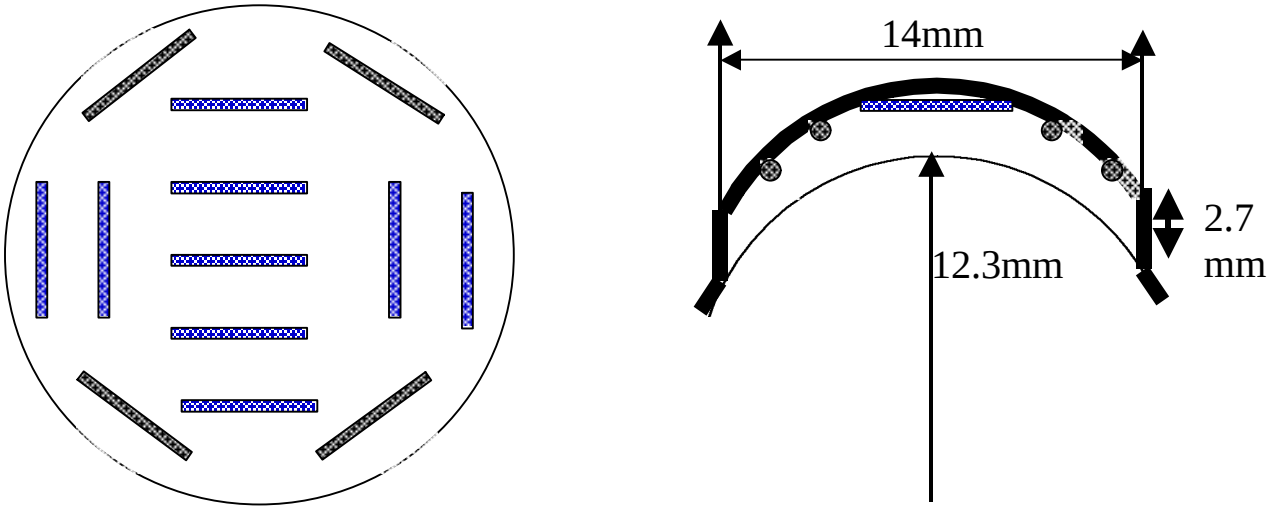

Fig. 4: Schematic diagram of seed arrangement for a 14 mm eye plaque

The distance between the surface of the eye and the centre of the source was considered as 1.4 mm which includes the radius of the seed and the thickness of the silicon seed carrier beneath the source. Dose computations were done for the points along the axis of the plaque at 1 mm interval. The line source geometry was considered for computing the radial distance between the point of interest and the centre of the source and the angle which the point makes with the axis of the source. Dose distribution in a plane 5 mm below the centre of the plaque axis was computed for different radial distances at 15^0 intervals. Isodose distributions have been plotted, normalizing the dose rate at the centre of the plaque at the same level.

Table 9: Dose rate from unit air kerma strength plaques of different diameters

Depth (mm)	Dose rate (cGy/h) from unit AKS plaques					
	12 mm dia. 8 seeds	14 mm dia. 12 seeds	16 mm dia. 13 seeds	16 mm dia. 16 seeds	18 mm dia. 21 seeds	20 mm dia. 24 seeds
0	3.981	3.358	2.903	2.941	2.663	2.300
1	3.854	3.343	2.926	2.915	2.678	2.296
2	3.538	3.259	2.864	2.795	2.636	2.209
3	3.150	2.939	2.586	2.616	2.441	2.073
4	2.639	2.442	2.216	2.195	2.101	1.874
5	2.071	1.946	1.813	1.805	1.733	1.586
6	1.651	1.572	1.498	1.494	1.445	1.353
7	1.338	1.286	1.248	1.245	1.214	1.161
8	1.098	1.065	1.048	1.046	1.028	0.998
9	0.909	0.887	0.882	0.880	0.871	0.858
10	0.758	0.744	0.746	0.744	0.740	0.739

Variation of central axis depth dose with plaque diameter from plaques of unit air kerma strength is given in Table 9. Multiplication of the dose rate value of Table 9 by the total air kerma strength of the source distributed over the plaque will give the dose rate at a given depth from a plaque with given source loading. At 5 mm depth, the dose rate per unit AKS from 12 mm diameter plaque is about 30% larger than that of 20 mm diameter plaque. However, at 10 mm depth, the dose rates from 12 and 20 mm diameter plaques are comparable to each other within a difference of about 1.5%.

Fig. 5 shows a comparison of the central axis depth dose of a 20 mm diameter ^{125}I plaque with the published values of similar size ^{106}Ru plaque (Cross et al 2001). ^{106}Ru has the advantage of steep dose fall off beyond the depth of interest. The dose rate at 10 mm depth from ^{106}Ru plaque is about 10% of the dose rate at 5 mm depth whereas it is about 45% for ^{125}I plaque. This difference in the dosimetry characteristics of ^{125}I and ^{106}Ru plaques indicates that ^{125}I plaque is suitable for treatment of deep seated tumours while ^{106}Ru plaque is suitable for treatment of superficial lesions.

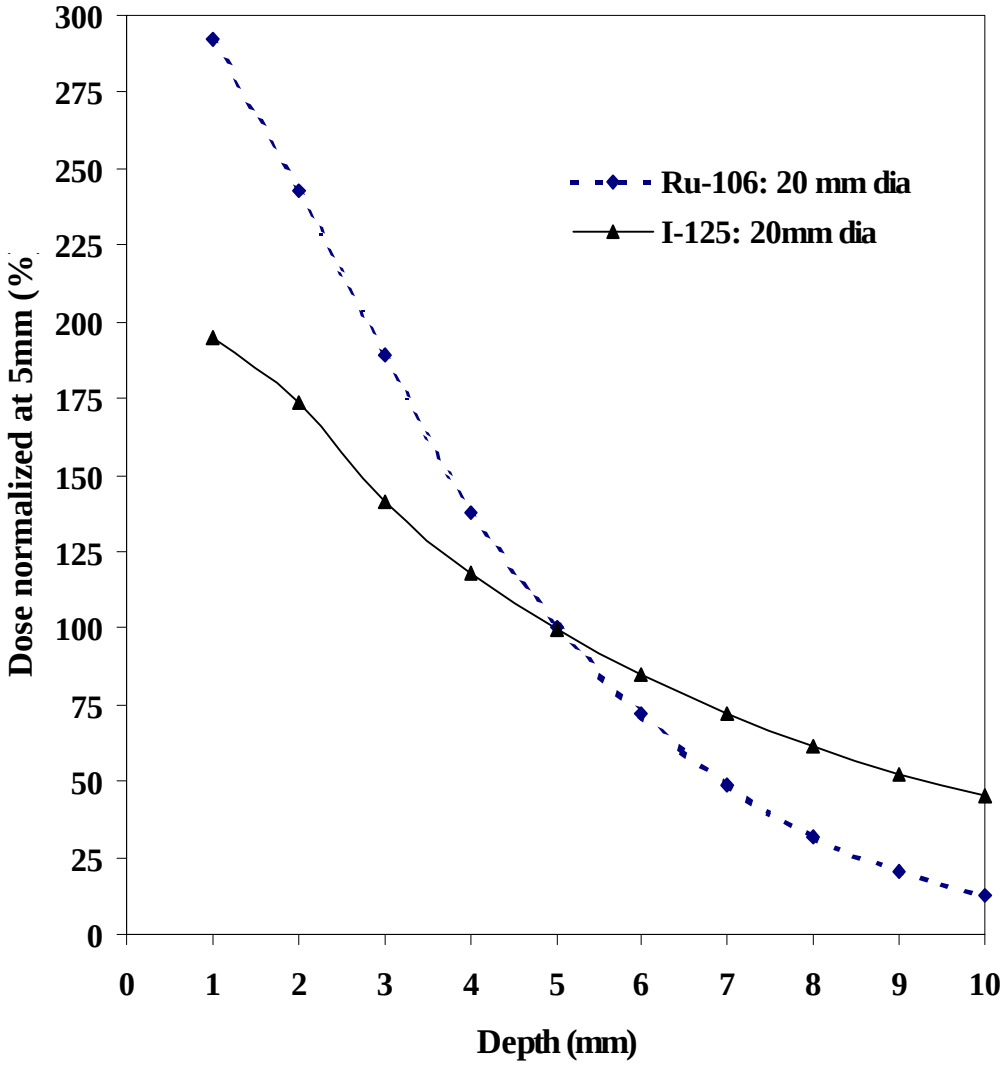

Fig. 5: Comparison of central axis depth dose of ^{106}Ru and ^{125}I eye plaques

The isodose distributions at 5 mm depth for the 20 mm diameter ^{125}I plaque are given in Fig. 6. The isodose distributions are almost circular in conformity with the shape of the eye plaque. It can be seen that about 65 % area of the plaque is enclosed by 90% isodose line and 80% area by 80% isodose line. The size of the plaque and reference dose should be based on the width of isodose surface at reference depth.

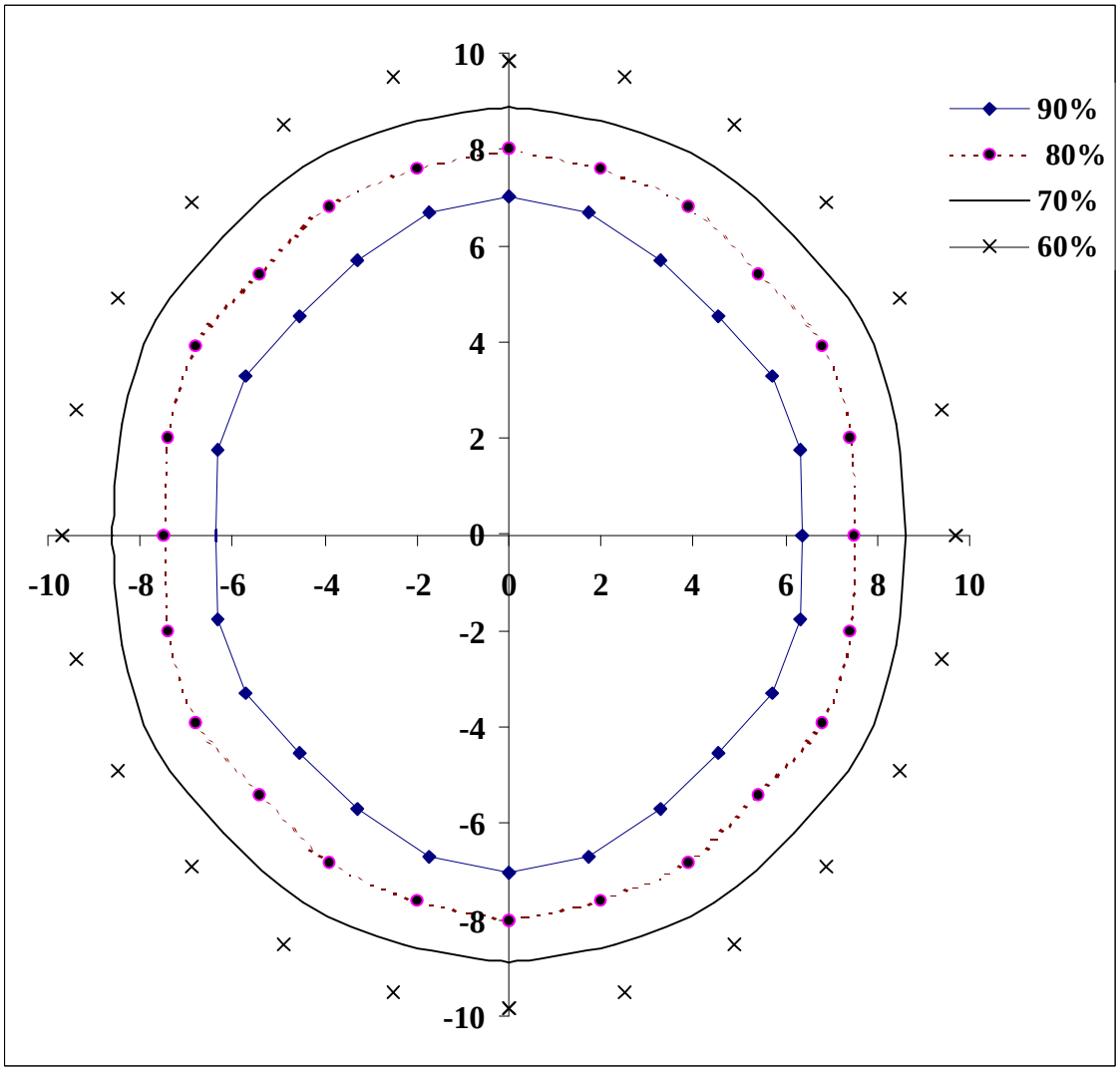

Fig. 6: Isodose distribution at 5 mm depth for a 20 mm diameter ^{125}I eye plaque

SECTION - V : QUALITY ASSURANCE AND RADIATION SAFETY DURING OPHTHALMIC APPLICATIONS

Quality Assurance

Quality control tests required for eye plaque therapy include quality control of sources, plaques and source inserts and treatment planning computer. In case of permanently loaded plaques, the test required prior to application is mainly the integrity of the plaque and the absence of any contamination. In the case of temporary loaded plaques, integrity of the sources, integrity of the plaques and the handling equipment should be thoroughly checked to ensure that no contamination is present on any working surface.

The quality control of plaques mainly focuses on the verification of source positions in seed carrier and radii of curvature of metallic backings and source inserts. These can be checked by taking orthogonal (AP and lateral) radiographs using dummy sources. The quality control of sources includes verification of physical dimensions of the sources, verification of source strength and leakage and contamination tests. As regards quality control of treatment planning system, the reconstructed position of sources and the dose rate at reference depth should be evaluated using dummy sources and verified.

Radiation Safety

All precautions necessary for routine brachytherapy applications should also be followed for eye plaque therapy. It includes separate rooms for source preparation and storage, application and treatment; availability of trained staff, measuring and monitoring instruments; and protective devices for source preparation and application. ^{106}Ru applicators are stored in a special storage cum transport container with locking facility. It should not be stored near material that may promote corrosion as high energy radiation may cause decomposition in materials such as plastics which can have destructive effect on the applicator.

The applicator must be handled very carefully. Inappropriate handling can lead to the risk of radioactive contamination of the patient and environment. The applicator must not be handled

with sharp or pointed devices. Scratching or otherwise damaging the surface must be avoided. The applicator should, therefore, be handled using tweezers with protective covering. If any deformation is noticed and/or leakage or removable activity is found, the applicator must be excluded from further use and the competent authority shall be informed accordingly. It is necessary to initiate appropriate action for safe disposal of the damaged and/or leaky sources after obtaining regulatory permission.

The maximum recommended working life of ^{106}Ru plaque is 1 year or 50 sterilisation cycles which ever is earlier. After its useful life, the applicator should be sent back to the supplier. A commitment to this effect should be obtained from the supplier before procuring the applicator. Alternatively, BRIT, DAE may be contacted and prior approval shall be obtained before sending the applicator for disposal.

After each application, the applicator should be cleaned with distilled water, ethanol or a neutral washing agent but under no circumstances should alkali or acid media be used for cleaning. It is essential to avoid body fluids drying onto the surface of the applicators. Should it not be possible to carry out cleaning immediately, the applicator must be stored in distilled water or ethanol. The source and the applicator must be completely dried before storing back in the storage container.

Eye plaque therapy using I-125 seeds is a manual afterloading technique and the activity used is of the order of 1- 2 GBq. The storage and preparation of sources should be carried out in a separate room identified for this purpose. A lead lined steel work bench similar to that used in nuclear medicine work is adequate for plaque preparation and source removal from plaque after treatment. As the half value thickness of ^{125}I in lead is 0.025 mm, the shielding required for the work bench is fraction of a millimeter of lead. The colour of encapsulation material is not easily distinguishable from that of the working surface a white tray (with sides a few inches high) is recommended for handling these seeds. Extreme care is necessary in handling these sources as it is very difficult to retrieve a seed if it falls accidentally. Specially designed jig should be used to hold the seed trough while loading the sources. To facilitate easy handling, sources of identical activity should be stored in groups in appropriate containers. The container design should be such as to facilitate easy extraction for preparation of the plaque. Lead lined long sleeved

gloves, long forceps and tweezers are other requirements for safe handling of seed sources. Hands-on training under a certified and experienced medical physicist is absolutely necessary to carry out the operation.

A safe method appropriate to the type of plaque should be used for sterilization of the plaque loaded with sources. Smooth and successful completion of the entire programme strongly depends on the proper communication among Radiation Oncologist, Medical Physicist, Ophthalmologist, OT Personnel and Nursing staff. The concerned staff should be monitored regularly for radiation safety. Radiation survey meter capable of measuring low energy gamma rays should be available during the entire operations. After the treatment, the number of seeds in the plaque should be verified and the patient surveyed. In the source preparation room, the source insert and metallic plaque are separated with a knife along the inner rim of the plaque. Individual seeds are removed and identified. The sources should be checked for leakage and contamination after removal from patient and/or before preparing for another patient. Unused sources should also be checked at least semi-annually. In case of leakage or deformity, the sources should be stored in an air-tight container and arrangements shall be made for their safe disposal. In case of rupture of ^{125}I seed, radioactive iodine may be released to the environment. If this happens, the seeds should be sealed in a container and the area of the accident should be put under lock and key. A fume hood is recommended to handle leaky sources to prevent the release of radioactive iodine in gaseous form. If contamination occurs, the area and personnel should be decontaminated and the personnel should undergo a thyroid scan.

A well-type ionization chamber, calibrated for ^{125}I seed, is recommended to verify the supplier quoted source strength. An appropriate dosimetry programme should be established for planning and dosimetry of eye plaque therapy.

The patient should stay in a separate room with proper label on the door. Unnecessary close proximity with the patient for prolonged periods should be avoided. The source handling room should preferably be on the same floor and not far from the OT. Because of the close proximity, while assembling and accounting seed sources, it is important to establish proper work environment with the following accessories:

1) An L-shaped work table with lead lining on the top and a lead viewing glass with proper illumination;
2) A calibrated beta-gamma survey meter/ contamination monitor;
3) Lead-lined long sleeved gloves, long stem forceps, tweezers; and
4) A fume-hood to handle ruptured ^{125}I seeds.

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APPENDIX

PROFORMA OF APPLICATION TO OBTAIN REGULATORY CONSENT FOR EYE PLAQUE THERAPY

1. Name and address of the Institution:
(Include Pin Code)

Fax: Tel.: e-mail:

2. Particulars of staff associated with the use of radioactive plaque:

(a). Clinician/Radiotherapist:

Name	Qualification(s)	Experience	Employee/Consultant

(b). Medical Physicist(s)/ Radiological Safety Officer:

Name	Qualification(s)	Experience	Employee/Consultant

3. Radionuclide used:
No. of sources and total activity:

4. Type pf plaque* : Permanent loaded /Temporary loaded
(Give a short description of the plaque - preparation, application and sterilization)

** Attach a copy of the catalogue from the supplier or give detailed specification of the plaque*

5. No. of patients per week:

6. Source handling facilities:

7. Layout of rooms with appropriate scale and preferably a site plan:
(On a separate sheet of paper give dimensional drawings of the rooms clearly marking the storage area, preparation room and treatment room)

8. Radiation Dosimeters/Surveymeters/Contamination monitors:

Name & Sr. No. of instruments	Make & Model	Date of Calibration

9. Procedure for disposal of the decayed sources:

10. Any other relevant information:

Name & Signature of the Head of the Department	Name & Signature of the Medical Physicist/RSO
Signature: Name: Date: Place:	Signature: Name: Date: Place:

Notes: (1) Duly completed application should be sent to the competent authority.
(2) Use additional sheets wherever required.