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Dose assessment to the Bladder during Intracavitary Brachytherapy of the Cervix using Gafchromic films

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ABSTRACT

Intracavitary brachytherapy procedures are used for cervical cancer treatment, by the insertion of radioactive implants directly into the diseased tissues. During the treatment process, the bladder together with surrounding tissues are exposed to radiations. Clinical complications do results from high doses received by parts of the bladder during intracavitary brachytherapy of the cervix. The aim of this study is to assess the dose delivered to the bladder using Gafchromic films and compare it with the optimized dose calculated by the Brachy Prowess 4.60 Treatment Planning System (TPS) reports for empirical validation and system verification. Fletcher suite applicators were used to perform thirty (30) different clinical insertions on the constructed cervix phantom and results evaluated. The mean difference between the doses calculated by the TPS and the doses measured by the Gafchromic film for the bladder at the distance of 0.5cm from the edge of the film was 16.3 % (range -35.33 to +39.37). At a distance of 1.5cm for the bladder, the mean difference was 19.4% (range -49.48 to +30.39). The TPS calculated maximum dose was typically higher than the measured maximum dose. However, in some cases, the measured doses were found to be higher than the doses calculated by the TPS. This is due to positional inaccuracies of the sources during treatment planning. It is recommended that in vivo dosimetry be performed in addition to computation.

Keywords : Bladder Dose, Applicators, Cervix Phantoms, Gafchromic Film

I. INTRODUCTION

Brachytherapy has plays a major role in the radical treatment of the cervical cancer, often combined with external beam radiotherapy, EBRT. It is the dominant element in the cure of early stages, whilst EBRT is used in advanced stages. Brachytherapy (sometimes referred to as curietherapy or endocurie therapy) is a term

used to describe the short distance treatment of cancer with radiation from small, encapsulated radionuclide sources. This type of treatment is given by placing sources directly into or near the volume to be treated. The dose is then delivered continuously, either over a short period of time (temporary implants) or over the lifetime of the source to a complete decay (permanent implants).

Most common Brachytherapy source emits photons; however, in a few specialized situations β or neutron emitting sources are used.

Intracavitary treatments are always temporary, of short duration, while interstitial treatments may be temporary or permanent. Temporary implants are inserted using either manual or remote *afterloading* procedures. Other, less common forms of Brachytherapy treatments include surface plaque, intraluminal, introperative and intravascular source applications; for these treatments either γ or β emitting sources are used. The physical advantage of Brachytherapy treatments compared with

external beam radiotherapy is the improved localized delivery of dose to the target volume of interest. The disadvantage is that Brachytherapy can only be used in cases in which the tumour is well localized and relatively small. In a typical radiotherapy department about 10-20% of all radiotherapy patients are treated with Brachytherapy. (E.B. Podgorsak. -Radiation Oncology Physics-P: 425).

Several aspects must be considered when giving Brachytherapy treatments. Of importance is the way in which the sources are positioned relative to the volume to treated, and several different models have been developed over the past decades for this purpose. The advantage of using a well-established model is that one benefits from the long experience associated with such models and that one can take advantage of published results. The use of uniform models and method in Brachytherapy treatments simplifies comparison of treatment results.

A typical treatment in which a model may be used is, for example, the treatment of cancer of the cervix, in which the dose is given to a specific point A, or low dose rate (LDR) treatments of head and neck cancers using Ir-192 wires. In this latter case the Paris model provides suitable guidelines for calculation of the treatment dose and time relative to the dose calculation points and on the source strength. In situations in which the system to be used is not obvious; the scientific literature should be consulted in order to take full advantage of already existing experience.

With the use of a specific method for the Brachytherapy treatment and a model for the dose distribution calculation, comparison of results is simplified. The use of a well-established dosimetric system for the treatment of cancer gives a common point for such comparisons. However, the use of a model alone is not sufficient to validate result; it is necessary to have a reliable method for determination of the source strength in order for the dose calculation to be accurate. This means that it is necessary for Brachytherapy sources to be calibrated, with the calibration traceable to a national or international standards laboratory.

In vivo dose measurements can be divided into entrance dose measurements, exit dose measurements and intracavitary dose measurements. Entrance dose measurements serve to check the output and performance of the treatment apparatus as well as the accuracy of the patient set-up; Exit dose measurements serve in addition to check the dose calculation algorithm and to determine the influence of the shape, size and density variations of the body of the patient on the dose calculation procedure; Sometimes it is also possible to determine the intracavitary dose in readily accessible body cavities such as the oral cavity, oesophagus, vagina, bladder and rectum. The most frequent clinical complications of intracavitary radiation treatments of cervical cancer result from a high dose delivered to the portions of the rectum and bladder that are in close proximity to the sources. Applicator placement with respect to the location of the rectum and bladder is therefore very important, in order to keep the dose to these critical structures as low as possible. In many instances surgical cotton gauze is used to displace the sensitive structures away from the applicators.

II. OBJECTIVES

The aim is to assess the absorbed dose to the bladder and compare it with the optimized dose calculated by the Brachy Prowess 4.60 Treatment Planning System (TPS) reports for empirical validation and system verification. In addition to:

- To determine the effect of shielding offered by the applicator on dosimetry.
- To determine appropriate recommendations for the minimization of radiation dose to patients undergoing treatment

III. MATERIALS

Locally fabricated cervix phantom from Perspex (PMMA) sheets, tape measure, Gafchromic films, PTW plastic water phantom (type 267), Colbalt-60 teletherapy machine, Low Dose Rate (LDR) Brachytherapy machine with Cesium-137 source, C-arm x-ray unit, Fletcher Suite of Applicators, Prowess 4.60 Treatment Planning System (TPS) and Densitometer.

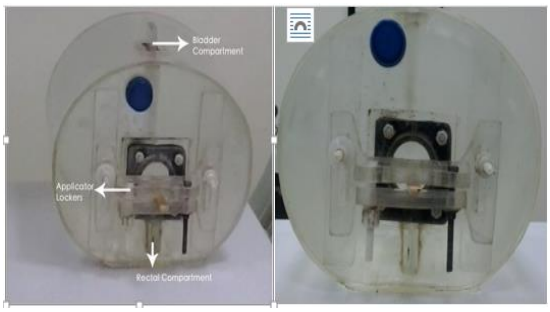


Figure 1: Cervix phantom

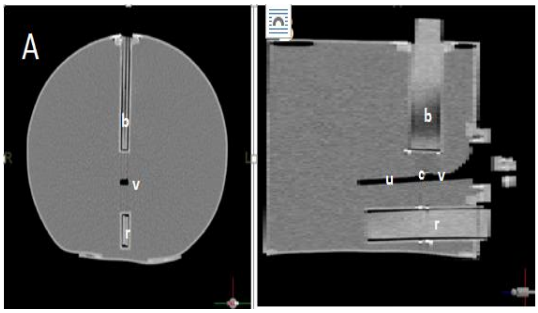


Figure 2: CT images of constructed phantom

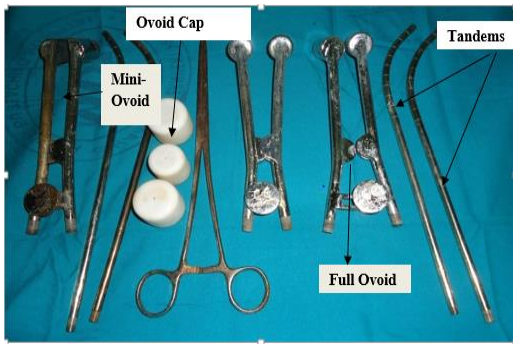


Figure 3: Fletcher Suite Applicators

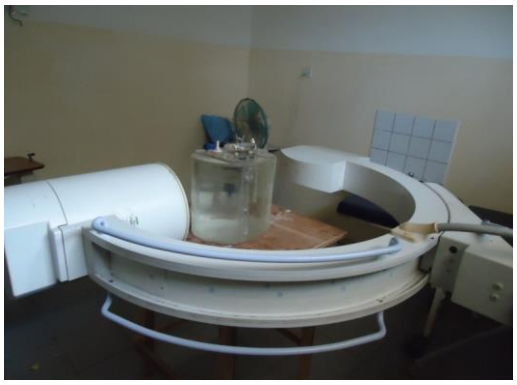


Figure 4: C-arm x-ray unit

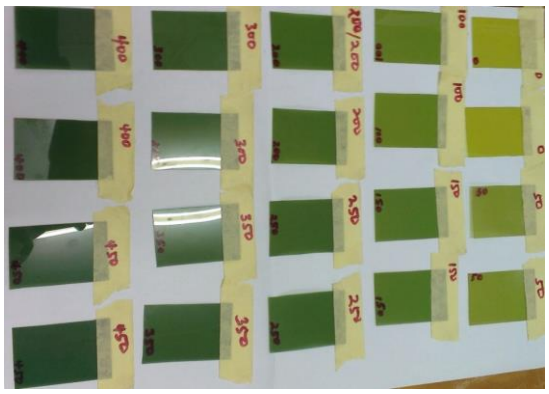


Figure 5: Gafchromic Films

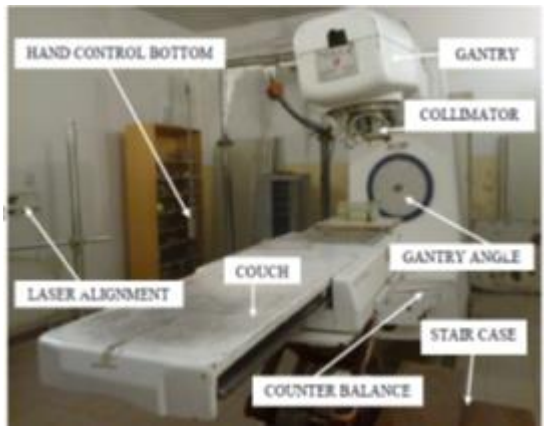


Figure 6: Co-60 Teletherapy

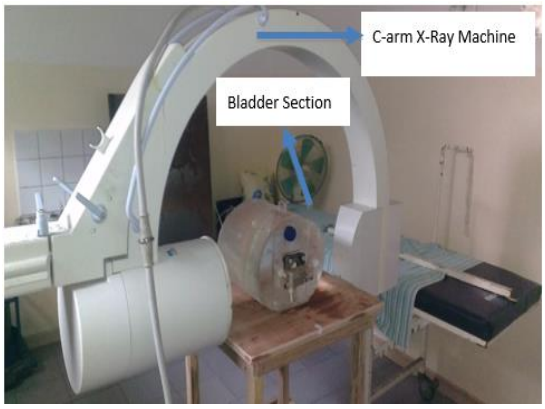


Figure 7: C-arm x-ray

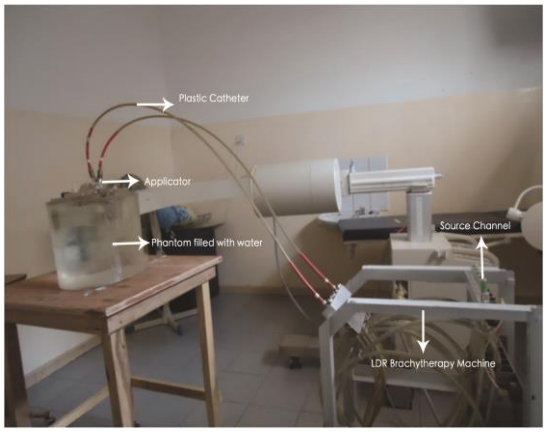


Figure 8: Experimental setup

IV. METHODOLOGY

The beam output was measured for the reference field size of 10 × 10 cm^2 at a depth of 5 cm for the cobalt 60 teletherapy unit using the PTW 30001 ionization chamber and the mini water phantom which had been filled with water. In filling the phantom it was ensured that they were no air bubbles trapped within the phantom. The beam output measurement or the beam

calibration was done in accordance to the IAEA Technical Report series (TRS) 389 protocol, as described in sections 2.5.1 of chapter two. Prior to the measurement, the stability of the ionization chamber was checked with a strontium 90 check source kit provided by the manufacturer of the ionization chamber. Also radiation and light field congruence test was performed with a MEDTEC iso-aligner and radiotherapy non-screen film to establish the accuracy of the field size parameters as well as that of the radiation for the teletherapy unit. The beam calibration was done with source-to-surface distance (SSD) irradiation technique, such that the SSD indicated by the optical distance measuring device on the gantry of the teletherapy machine read 80 cm on the surface of the phantom. The phantom was positioned on the couch of the teletherapy unit and the flatness of the surface of the phantom checked with a spirit level. The position of the phantom was adjusted such that the field size inscribed on the surface of the phantom matched that of the light field of the teletherapy machine. The ionization chamber was inserted in to the hole provided for it on the phantom, and the chamber aligned such that a line inscribed on its stem coincided with that on the mouth of the hole where the chamber was inserted. This was to ensure reproducibility of the irradiation geometry which was used to calibrate the ionization chamber. The ionization chamber was perpendicular to the direction of propagation of the beam. The ionization chamber was connected to the PTW UNIDOS electrometer which was set to read charges in "STA" mode. Before the start of the measurement, the ionization chamber was pre-irradiated for 6 minutes to remove all stray charges in the chamber. The initial and final temperatures of the phantom were determined with a digital thermometer manufactured by Extech Instruments, China with serial 39240 before and after the measurements respectively. Pressure within the treatment room was measured with an anaerobic barometer manufactured by PTW Freiburg with Serial number 98889. Measurements were done for ten consecutive readings, and the mean reading corrected for influencing factors stated in Table 5 of Appendix B. For each reading, a treatment time of 60 seconds was set on the teletherapy unit console, and the electrometer set to start reading (by press "STA" on the front panel of the electrometer) before the beam was put on. This was done to ensure that timer error associated with the cobalt 60 teletherapy unit was accounted for in the final absorbed dose measured. The corrected meaning reading was used to calculate absorbed dose to water at the depth of measurement per minute base on IAEA TRS 398 protocol.

Absorbed dose determination

The plastic water phantom of dimension 30 ×30 ×25 cm^3 was set up on the couch of the cobalt 60 teletherapy unit such that the pile of slabs forming the phantom were held in place by gravity. The 30 x30x 2 cm^3 slab with a hole at one of its sides to accommodate 0.6 cc farmer type ionization chamber was placed among the pile of slabs forming the phantom. The slab was placed such that the distance from the surface of the phantom to the centre of the hole on the slab was 5 cm. The flatness of the phantom was checked with the spirit level to ensure normal beam incidence. The 0.6 cc ionization chamber which was connected to the PTW UNIDOS electrometer was inserted into the hole provided for it on the phantom. The phantom was aligned such that the beam central axis coincided with the centre of the phantom, which was done with the aid of the patient alignment systems of the teletherapy unit and special indentation marks placed on one of the slabs of the phantom.

Using the same irradiation geometry as that used for the beam calibration, the ionization chamber was irradiated for treatment times of 60 seconds set on the teletherapy unit console. Charges were read with the electrometer using the same procedure outlined for the beam calibration. Ten (10) successive readings were taken and the mean reading calculated. The temperatures of the phantom before and after the irradiations were measured with the digital thermometer. The room pressure was measured the anaerobic barometer. The mean reading was therefore corrected for temperature and pressure effects.

The corrected mean reading obtained was compared to that of the beam calibration and the ratio of the two values computed. The ratio obtained was set as the scaling factor for the treatment depth of 5 cm for measurements done with the plastic phantom, since the plastic water phantom was not made from a perfect water equivalent material (in terms of radiological properties).

V. BLADDER DOSE ASSESSMENT

Typical clinical implants (or insertions) for cervical intracavitary brachytherapy were performed on the fabricated cervix phantom with the Fletcher suite of applicator. Procedures and protocol in use at the oncology centre were adhered to during the implementation of the implants.

In inserting the applicators into the host, the volume of water in the phantom was halved to reduce pressure on the latex rubber tube forming the vagina walls. After the insertion and the applicators held in place, the phantom was refilled. The filling was done such that the phantom was devoid of air bubbles, the air bubbles detected were allowed to migrate to the opposite end of the phantom with the vagina orifice. Imagings were done for the phantom with the applicators in place with the C-arm x-ray machine. For each implant two radiographs orthogonal to each other were taken for treatment planning to determine dose rates to prescription points (see figures 3.11 and 3.12). The dose prescription points were as follows; for implants including a tandem the prescription point was point A. For ovoids only the prescription points were to the surface of the ovoids and depth of 0.5 cm from the surface of the ovoids. These prescription points are currently in use by the oncology centre.

Thirty (30) different applicator configurations that are often used in clinical applications were implemented on the phantom. For each applicator configuration implemented on the phantom, strips of Gafchromic films from the same lot# that was calibrated were cut to the required size, such that they fitted perfectly into the compartments of the phantom mimicking the bladder. The films were then sandwiched between the Perspex slabs of the respective compartment, and then the films and slabs inserted into their corresponding compartments. Films were cut to sizes of 9×3.8cm and17× 3.6cm for the bladder. Prior to the insertion of the films it was ensured that the compartment was dried to prevent discoloration of the film particularly at the edges. The placements of the films inside the phantom were done after the imaging process.

The applicators were connected to catheters in use for the applicators, and the catheters connected to their respective channels on the AMRA brachytherapy machine (figure 3.13). The ovoids were connected to channels V1 and V5. For an implant with uterine tube or tandem, the channel to use was selected based on the length of the tandem which had protruded beyond the midpoint of the ovoid viewed on the lateral radiograph of the implant and also taking magnification into consideration. Channel U2 was chosen for the smallest length; U3 for medium length; and U4 for the longest length. After connecting the catheters to their respective channels, the selected channels were engaged and treatment initiated with the manual afterloading mechanism of the brachytherapy machine. Time at the start and end of each treatment were then noted. The exposure time for the films or the treatment time ranges from a day to two.

Procedures for the identification of source positions on the orthogonal radiographs and the digitization of these positions into the treatment planning systems in use at the oncology centre were strictly followed during the treatment planning of the brachytherapy implants carried on the phantom. The special radio-opaque marks placed within the phantom were used to identify calculation points on the films, which were also digitized for dose rates to be determined for those points. The points were 0.5 cm and 1.5 cm from the edges of the films towards the applicators for the bladder.

These points were in line with the marks placed within the phantom. The edges of the films were easily identifiable on the radiographs due to the way the compartment for the bladder was designed. These points were therefore identified on the exposed Gafchromic films, and the same densitometer which was used in the film calibration was used to read optical densities of films at the identified points. The readings of the films were done 24hours after exposure. The optical densities obtained were converted to doses using the calibration equation obtained from the sensitometric curve. The dose rates calculated with the TPS for the points were also converted to doses by multiplying the dose rates with the treatment time.

1) **The doses calculated with the TPS were compared with the measured ones with the densitometer, and the percentage errors determined as:**

$$\%\ error = \frac{TPS\ dose - Film\ Dose}{TPS\ dose} X100$$

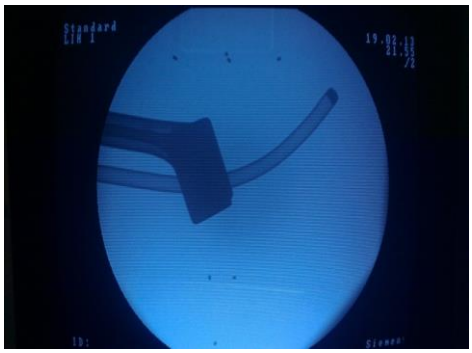


Plate 3.14: Lateral radiograph of applicator insertions obtained from one of the set-ups. [Field work 2013]

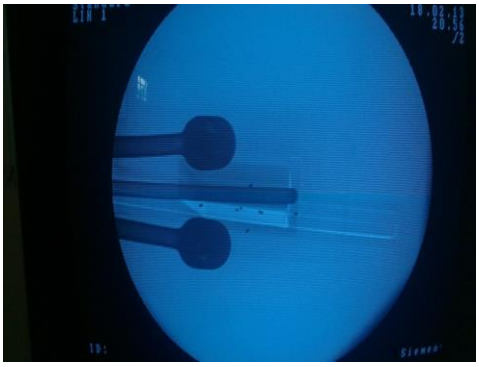


Plate 3.15: Anterior-posterior radiograph of the applicator insertions obtained from one of the experimental set-up. [Field work 2013]

Plate3.16: Orthogonal radiograph of clinical insertions with a tandem, dose prescribed to point A, sources positioned in the ovoids and tandems. [Field work 2013]

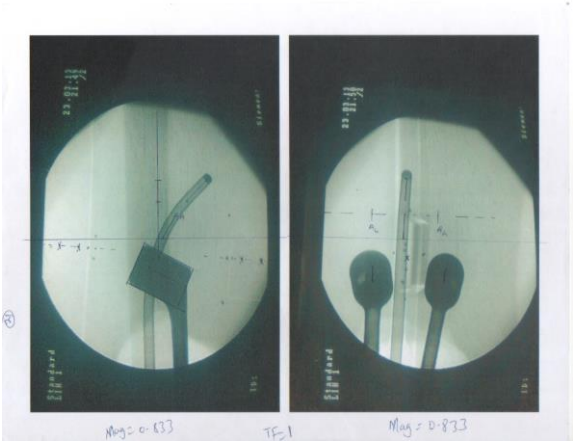
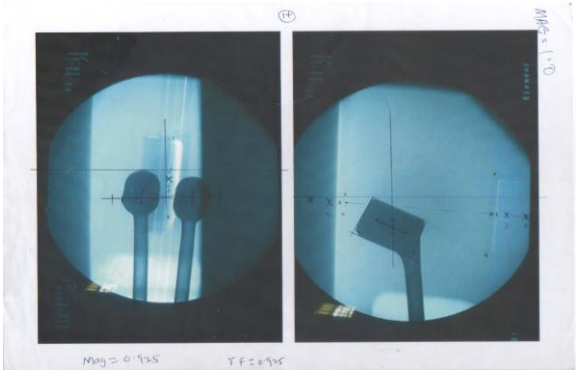


Plate3.17: Orthogonal radiograph of clinical insertions with only ovoid, dose prescribed to the surface of the ovoids and 0.5cm from the surface of the ovoid. [Field work 2013]



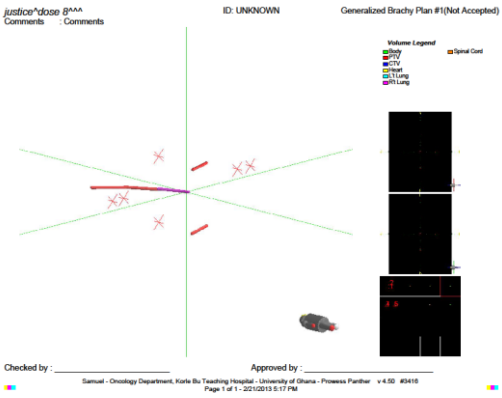


Plate 3.18: A pictorial view of superimposed calculation points from the TPS.

the TPS are expressed as a percentage difference of the dose measured by the TPS

Table:1 Summary of Results

Comparison of dose calculated by the TPS with dose measured by the film at 0.5 cm and 1.5 cm from the edge of the film for the bladder.

	Bladder			
	Distance from edge of film (cm)			
	0.5		1.5	
Insertions	Diff (cGy)	% Diff	Diff (cGy)	% Diff
Mean	33.29	16.28	22.45	19.35
MIN	-63.61	-35.33	-62.63	-49.48
MAX	172.70	39.37	61.72	30.39

VI. DISCUSSIONS

The summary of the differences between the doses calculated and the doses measured are shown in Table 1.

The doses calculated by the TPS are then compared to the doses measured by the Gafchromic film. The main objective of this research was to assess the absorbed dose to the bladder using Gafchromic films and compare it with the calculated dose by the treatment planning system (TPS) for system verification. Thirty insertions were carried out on the phantom and evaluated. The mean difference between the doses calculated by the TPS and the doses measured by the Gafchromic film for the bladder at the distance of 0.5cm from the edge of the film was 16.3 % (range -35.33 to +39.37). At a distance of 1.5cm for the bladder, the mean difference was 19.4% (range -49.48 to +30.39). The study showed that the TPS calculated maximum dose was typically higher than the measured maximum dose.

However, in some cases, the measured doses were found to be higher than the doses calculated by the TPS. These deviations are due to positional inaccuracy of the sources. The imaging technique used at the Centre cannot locate the exact position of the sources. This is because the c-arm x-ray facility used is automated making the technique variables fixed, preventing the x-ray energy from being altered, making it difficult to take the required radiographs in order to locate the positional accuracy of the sources. During treatment planning the sources are assumed to be in the Centre of the applicators which is not necessarily the case. Since the doses were measured at distances of 0.5cm and 1.5cm respectively, once the assumed positions of the sources are not accurate, one will definitely encounter deviations in the dose measurement, because a slight deviation in distance will mean a higher or lower deviation in dose. Again, during imaging, dummy needles must be used to view the dwell places and the exact positions of the sources but the kind of applicators used at the Centre makes it difficult to do so. Modern plastic applicators make visualization of sources easier in order to determine their exact positions.
Another objective of this study was to determine the effect of shielding on dosimetry. The data obtained suggest that generally dose reduction to the bladder was low, due to the clinical insertions and because of the anatomy of the cervix.

The shielding provided in the applicators is another factor responsible for this dose variation. The tungsten shield provided in the Fletcher suite applicators to reduce dose to critical organs has been a major contributing factor to the dose deviation in this study. It is evident from the data obtained that the shields reduce dose drastically. In fact dose perturbation due to applicator shielding especially could be dramatic with differences as high as 50%. Many researchers, like J.F. Williamson (1990) have performed Monte Carlo calculations around a single Fletcher Suite Delclos (FSD) ovoid and evaluated dose reductions as large as 50% due to the shielding provided in these applicators. Meli JA et al have also reported that Gynaecology applicators with bladder and rectal shields achieve dose reductions as large as 25% at some locations; their dose reduction characteristics are well documented. Faiz M. Khan and Roger A. Potish reported (1998) that attenuation from Cs-137 sources in intrauterine tubes (tandems) alone measures as much as 5% dose deviation depending on the angle but this is a commonly neglected effect. Interestingly, the mathematical algorithm used by the TPS failed to account for the shielding provided in these applicators. This deviation however shows that the centre is working within the acceptable limit.

Another reason for dose variation in this study has to do with the source strength. There is an incorporation of deviation and manufactures quoted value.

The exact source strength for the Cesium-137 in use is not known. It is the manufactures' quoted value that is being used for the treatment planning and this has some level of deviation.

There was no calibration done to determine the exact source strength. The National Centre for Radiotherapy and Nuclear Medicine (NCRNM) did not have the ionization chamber needed for the calibration. It was in 2009, that the International Atomic Energy Agency (IAEA) gave the NCRNM a well type ionization chamber designed for High Dose Rate (HDR) which of-course could not be used for the calibration of the LDR due to the discrepancies in the length of the well. So the centre is still using the manufacturer's quoted value which has an uncertainty of 2.5%. This is highly responsible for the dose variation encountered in this study.

Some researchers found out that the mean deviation from the manufacturer's value could be as high as 2.47 for each source. The LDR brachytherapy machine has five channels. In all clinical insertions, a maximum of three channels were used. This implies that dose

deviation resulting from this unknown source strength is 7.41%. Jacek G. Wierzbicki and Richard Meyer (1991) performed a routine verification of the strength of Cs-137 brachytherapy source and found out that the uncertainty of the source strength was 2%. Cs-137 brachytherapy sources usually have vendor supplied calibrations that should be verified by the user. In addition to this, routine calibration of brachytherapy sources should be done annually. It is important that in quality control the different sources from different batches should not be confused based upon the original vendor-specified source strength supplied at the time of original purchase.

The centre is still using the old system of practice where images are being digitized by the medical physicist before treatment planning. Before digitizing, the source positions and calculation points are manually determined. Hence calculation of image magnification and transfer factors have contributed some level of error during treatment planning which eventually affect the dose rate from the TPS. This is because of the blurring nature of some images obtained from the set-up makes it a bit difficult sometimes to obtain the exact magnification and transfer factors for the images. In modern practice, orthogonal images obtained from patients' set-up are transferred directly to the TPS by networking and this limit human error because it is believed that most uncertainties that occur during brachytherapy procedure are human based.

Another factor that contributed to dose reduction was the applicator shift in the elapsed time between the imaging and the treatment stage. This is because in Intracavitary brachytherapy a slight shift in positions of the applicators results in significant deviation of dose. These dose deviations evaluated are within the acceptable limit of brachytherapy practices.

VII. CONCLUSION

Dose to the bladder was assessed in intracavitary brachytherapy of the cervix by the irradiation of the cervix phantom constructed. Thirty (30) clinical insertions were carried out and the highest mean dose difference between calculated and measured dose was determined at the distance of 0.5cm from the edge of the film was 16.3 % At a distance of 1.5cm for the bladder, the mean difference was 19.4%. These variations in dose are within the acceptable limit. Ideally, in intracavitary brachytherapy of the cervix, where Fletcher suite applicators are used, dose variations as large as 25% are expected. In fact dose perturbations generally in brachytherapy do go as high as 50%. It was also realised that shielding provided in the ovoids have greatly reduce the radiation dose delivered to the bladder during intracavitary brachytherapy of the cervix. In order to achieve accurate patient dosimetry, the ovoid shields must be included in the dose model (algorithm). Dose assessments to the bladder during clinical irradiation showed that the variations between the TPS dose and measured dose were within the acceptable limit, so the intracavitary brachytherapy practises at the NCRNM is safe. The locally-constructed phantom used in this study, gave good results therefore, so the importation of phantoms for dosimetry measurements which makes research sometimes very expensive must be discouraged.

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